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IDA PAPER P-2173

ACQUISITION OF CONTEMPORARY TACTICAL MUNITIONS

Volume I: Summary Report

David C. Gogerty
Bruce M. Miller
J. Richard Nelson
Paul R. Palmer, Jr.

March 1990

Prepared for
Office of the Under Secretary of Defense (Acquisition)

IDA

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This Paper has been reviewed by IDA to assure that it meets the high standards of thoroughness, objectivity, and appropriate analytical methodology and that the results, conclusions and recommendations are properly supported by the material presented.

UNCLASSIFIED

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
March 1990

3. REPORT TYPE AND DATES COVERED
Final Report, Aug 1987 – Jun 1989

4. TITLE AND SUBTITLE
Acquisition of Contemporary Tactical Munitions, Volume I: Summary Report

5. FUNDING NUMBERS
C-MDA903-84C-0031
T-G7-535

6. AUTHOR(S)
David C. Gogerty, Bruce M. Miller, J. Richard Nelson, and Paul R. Palmer, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Institute for Defense Analyses
1801 N. Beauregard Street
Alexandria, VA 22311-1772

8. PERFORMING ORGANIZATION REPORT NUMBER
IDA-P-2173

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
OUSD(A)
Room 1E482, The Pentagon
Washington, DC 20301

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12A. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12B. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This paper presents the results of a study of the acquisition programs of 19 contemporary tactical air-and surface-launched munitions. The purpose of the study was to measure the outcomes of those programs in terms of the growth in development and production schedules and costs. Volume I of the paper presents the results of the analyses of program outcomes, characteristics, and acquisition policies. Volume II contains 13 case studies covering the 19 munitions in the study.

14. SUBJECT TERMS
Tactical Weapons, Acquisition, Production, Development, Costs

15. NUMBER OF PAGES
190

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

UNCLASSIFIED

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Contract MDA 903 84 C 0031
Task T-G7-535

PREFACE

This report was prepared by the Institute for Defense Analyses (IDA) for the Office of the Under Secretary for Defense (Acquisition) under contract MDA 903 84 C 0031, Task Order T-G7-535, issued 1 July 1987, and amendments. The objective of the task was to conduct case studies of ongoing acquisition programs in order to determine the extent to which cost, schedule, and other predictions have been accurate.

The intent of this two-volume report is to identify the characteristics associated with problems and successes in the acquisition of tactical munitions. Comparisons of the acquisition process between the munitions included in the sample are reported in Volume I. Volume II consists of individual case studies of the acquisition process for each of the munitions included in the sample.

The report was reviewed by Dr. Richard E. Schwartz, Dr. John E. Hove, and Mr. Stanley A. Horowitz of IDA. Mr. David C. Gogerty, who performed much of the analyses for this study, is an IDA consultant.

EXECUTIVE SUMMARY

A. OBJECTIVE AND APPROACH

Contemporary tactical munitions acquisitions have generally suffered substantial technical, schedule, and cost difficulties in attempting to achieve successful operational capabilities. For the most part, these operational capabilities have been realized after considerable grief in the development and production processes. The Office of the Under Secretary of Defense (Acquisition) requested this study to examine the causes of outcomes for selected tactical munitions and to document lessons learned from them. The objectives of this task were therefore to:

- Determine how substantial these difficulties were primarily in terms of cost growth and schedule slippage in development and procurement;
- Investigate how the difficulties originated and why they seem to recur;
- Address what might be done about them.

The approach was to examine nineteen new and modified contemporary tactical munitions from thirteen families, using information from:

- Selected acquisition reports and other readily available literature;
- Program offices and contractors.

A modified munition is defined here as a significantly improved version of an operational munition. For example, the Sparrow AIM-7F was a major modification in the sequence of Sparrow missiles. Modification programs have mostly been addressed as relatively straightforward extensions of existing programs. However, tactical munitions modifications generally involve improvements to the guidance and control sections, and these subsystems often represent two-thirds to five-sixths of the total cost of the munitions, so modification programs can be very large.

The selection criteria for the thirteen families of munitions were:

- Still in the inventory (except Deadeye Five-Inch Guided Projectile);
- Availability of *Selected Acquisitions Report* (SAR) data;
- Mixture of air- and surface-launched, intercept, and surface attack;
- Representation by each service and several major contractors.

The nineteen munition acquisition programs are documented in thirteen case studies in Volume II of this paper. The outcomes are summarized here in Tables ES-1 and ES-2. Relationships between measures of the acquisition program outcomes, measures of program risks, types of munitions, and applicability of acquisition policies were investigated using non-parametric statistical methods, and the results are documented in Volume I. The findings are sensitive to the limitation of the database; sample size was not large enough to establish the statistical significance of many of the observed differences in outcomes, risks, and policy application.

B. MAJOR FINDINGS

The analysis of the nineteen munition acquisition programs showed that:

- Modifications were much less expensive to develop than were new munitions. Average development cost for modified munitions was about one-third of that for new munitions. The highest actual development cost for a modification was less than two-thirds the average development cost for new munitions. Among the technically demanding air-launched intercept missiles, the development cost for each of the six modifications was at least 35 percent less than the lowest of the development costs for either of the two new missiles.
- Development program outcomes, in terms of schedule, quantity, and cost growth, were on average as bad or worse for modifications than for new munitions. Difficulties in developing modifications tended to be greatly underestimated. Development quantities for modified munitions increased by an average of 83 percent over the initial estimates, because of unrealistically low initial estimates of test article requirements for several air-launched intercept missile modifications. Development quantities for new munitions were initially estimated much more realistically, and subsequently decreased by an average of 16 percent; large numbers of test articles initially planned for several surface-launched surface attack munitions were later reduced. While average development cost growth for modified munitions was almost double that for new munitions, the difference was not statistically significant. Development schedule slippage did not differ significantly between new and modified munitions. Production cost growth and total program cost growth did not vary significantly between new and modified munitions. These results strongly suggest that acquisition programs for munitions modifications are equally as deserving of strict management attention and procedures as acquisition programs for new munitions.

Table ES-1. Summary of Acquisition Program Schedules, Costs, and Quantities

Designator	Name	Advanced Development (Months)	Full Scale Development (Months)	Development Quantity	Development Cost (89$ Millions)	Production Cost (89$ Millions)	Currently Planned Production Quantity	Currently Planned Production Span (Months)	Total Program Cost (89$ Millions)
A/RIM-7E	Sparrow IIIB CW		47	44	62.1	2,126.8	19,661	137	2,188.9
AIM-7F	Sparrow III Pulse Doppler		124	134	356.3	3,645.8	16,145	83	4,002.1
A/RIM-7M	Sparrow III Monopulse	38	57	44	94.0	2,749.0*	15,274*	82*	2,843.0*
AIM-9L	Sidewinder		81	123	195.4	1,609.5	11,350	113	1,804.9
AIM-9M	Sidewinder		79	134	134.2	1,321.4*	16,937*	139*	1,455.6*
AIM-54A	Phoenix	75	56	37	552.1	2,724.6	2,285	106	3,276.7
AIM-54C	Phoenix		122	45	234.9	3,358.7*	3,356*	141*	3,593.6*
AIM-120A	AMRAAM	46	94*	111*	1,299.9*	8,281.2*	24,320*	I.U.*	9,581.1*
FIM-92A	Stinger-Basic	I.U.	105	179	317.2	2,971.4*	8,085	I.U.	3,288.6*
FIM-52A	Stinger-POST/RMP		134*	29*	182.2*		42,555*	120*	
AGM-65D/F/G	IIR Maverick	I.U.	113	33	236.7	6,539.5*	60,664*	186*	6,776.2*
A/R/UGM-84A/C/D	Harpoon	33	50	52	895.8	4,639.0*	3,971*	229*	5,534.8*
AGM-88A	HARM	45	69	99	569.2	4,022.9*	14,438*	131*	4,592.1*
AGM-114A/B	Hellfire	45	125	229	506.8	1,347.3*	48,696*	138*	1,854.1*
BGM-71A	TOW I	17	89	472	422.5	3,025.4*	137,275*	166*	3,447.9*
BGM-71D	TOW II		61	113	179.6	2,434.7*	125,856*	126*	2,614.3*
–	MLRS	32	70	470	466.0	4,345.0*	452,322*	148*	4,811.0*
M-712	Copperhead CLGP	40	90	320	296.4	1,447.2*	24,546*	106*	1,743.6*
–	5" Deadeye SALGP	I.U.	49	141	209.7	N.A.	N.A.	N.A.	N.A.
Low		17	47	29	62.1	1,321.4	2,285	82	1,455.6
High		75	134	472	1,299.9	8,281.2	452,000	229	9,581.1
Mean-New		42	80	211	553.6	3,644.9	79,549	146	4,236.7
Mean-Modification		38	91	78	186.2	2,973.2	34,644	125	3,159.8
Mean-Overall		41	85	148	379.5	3,328.8	57,096	134	3,729.9

I.U. - Information unavailable.
N.A. - Not applicable.
* - SAR estimate.

Table ES-2. Summary of Acquisition Program Outcomes

Designator	Name	New/ Mod	Operational and Technical Requirements Satisfied	Development Schedule Growth Factor	Development Quantity Growth Factor	Development Cost Growth Factor	Quantity-Adjusted Production Cost Growth Factor	Production Quantity Growth Factor	Production Stretchout Factor	Quantity-Adjusted Total Program Cost Growth Factor
A/RIM-7E	Sparrow IIIB CW	Mod	Yes	1.00	1.00	0.84	I.D.	0.34	9.15	I.D.
AIM-7F	Sparrow III Pulse Doppler	Mod	No	2.82	3.94	4.27	I.D.	1.66	0.74	I.D.
A/RIM-7M	Sparrow III Monopulse	Mod	No	1.46	1.00	0.98	1.31	1.38	1.17	1.29
AIM-9L	Sidewinder	Mod	No	2.45	4.10	4.89	2.12	1.23	2.25	2.31
AIM-9M	Sidewinder	Mod	No	1.01	1.94	2.04	1.01	2.27	1.07	1.10
AIM-54A	Phoenix	New	No	1.19	0.82	1.54	1.35	0.98	1.00	1.38
AIM-54C	Phoenix	Mod	Yes	1.45	1.50	1.67	2.01	4.76	0.34	1.94
AIM-120A	AMRAAM	New	Unknown	1.74	0.66	1.40	I.D.	I.D.	I.D.	I.D.
FIM-92A	Stinger-Basic	New	Yes	1.64	0.81	1.46	1.45	0.35	2.86	1.45
FIM-92A	Stinger-POST/RMP	Mod	Unknown	1.06	1.00	2.34	I.D.	1.90	0.88	I.D.
AGM-65D/F/G	IIR Maverick	Mod	Yes	1.98	0.94	1.07	1.58	1.95	1.10	1.52
A/R/UGM-84A/C/D	Harpoon	New	No	1.35	1.00	1.06	1.93	1.38	2.21	1.63
AGM-88A	HARM	New	No	1.21	1.00	1.42	1.39	1.05	1.31	1.39
AGM-114A/B	Hellfire	New	No	1.44	0.95	1.09	1.61	1.98	1.20	1.39
BGM-71A	TOW I	New	No	1.51	1.01	1.20	I.D.	0.59	3.85	I.D.
BGM-71D	TOW II	Mod	Yes	1.02	1.00	1.70	0.96	0.89	1.31	0.99
–	MLRS	New	No	1.00	0.72	1.03	I.D.	1.25	1.19	I.D.
M-712	Copperhead CLGP	New	Yes	1.73	0.78	1.28	2.23	0.19	5.56	2.12
–	5" Deadeye SALGP	New	Yes	1.00	0.65	1.16	N.A.	N.A.	N.A.	N.A.
Low				1.00	0.65	0.84	0.96	0.19	0.34	0.99
High				2.82	4.10	4.89	2.23	4.76	9.15	2.31
Mean-New			0.30	1.38	0.84	1.26	1.66	0.97	2.40	1.56
Mean- Modified			0.44	1.58	1.83	2.20	1.50	1.82	2.00	1.53
Mean-Overall			0.41	1.48	1.31	1.71	1.58	1.42	2.19	1.54

N.A = Not applicable.
I.D. = Insufficient data.

- Development quantity growth and development cost growth were significantly lower for munitions that underwent advanced development. However, it is difficult to separate the effects of advanced development from whether the munition was new or modified. All of the new munitions underwent advanced development, while only two of the modifications did. Development quantity growth and development cost growth were lower for the modifications that underwent advanced development, but the sample size was too small to show that the differences were statistically significant.
- Competition during advanced development did not result in statistically significant differences in any of the acquisition program outcome measures. Competitive advanced development efforts may have been focused on the follow-on FSD contract rather than on reducing technological risks.
- Competition at the subsystem level during full scale development was associated with lower development cost growth. None of the munitions in the sample had competition at the system level during full scale development.
- Production competition at either the system or subsystem level had no discernable effect on production cost growth.
- The extent of the overlap between development and production was positively correlated with production cost growth.
- Production cost growth was directly correlated to overall DoD procurement total obligational authority (TOA) over the production span for each munition.
- No statistically significant effects on any of the program outcome measures could be discerned for independent testing or multi-year production contracting.

Other significant findings are summarized in the following two sections.

C. PROGRAM OUTCOMES

Acquisition program outcomes did not differ significantly between types of munitions, between new and modified munitions, or over time, except as otherwise noted. The following significant outcomes were observed:

- Total program cost growth averaged 54 percent, and was highly correlated with production cost growth.
- Development schedules slipped by an average of 48 percent, and that slippage involved development problems that subsequently adversely affected production costs.

- Development costs increased by an average of 71 percent, and that increase was directly correlated with development quantity growth. Development cost growth was not correlated with development schedule growth for the munitions in the sample. Development cost growth for intercept munitions was significantly higher than for surface attack munitions; several intercept missile modifications had unrealistically low initial development cost estimates, while the initial development cost estimates for new surface attack munitions were much more realistic.
- Production costs for the quantities that were originally estimated at the start of development increased by an average of 58 percent. That increase was directly correlated with development schedule growth, but was not correlated with growth in either development costs or development quantities.
- Production quantities increased by an average of 42 percent, and that increase was not significantly correlated with any other program outcome measure. Production quantity growth increased during the defense buildup of the early 1980s.
- Production stretchout, defined as the average increase in time between delivery of each unit, averaged 119 percent. That increase was not significantly correlated with any of the other program outcome measures. Production stretchout decreased during the defense buildup of the early 1980s.
- Operational and technical requirements specified in the SARs were fully satisfied by less than half of the munitions that had completed development. Because some munitions were deployed without fully satisfying the requirements, the requirements may have been unduly stringent. Production quantity growth did not differ significantly between the munitions for which the requirements were not satisfied and the munitions for which the requirements were satisfied.

D. EFFECTS OF PROGRAM RISKS

Information provided by contractors on technology advance and resource requirements expectations and actual outcomes for eleven of the munition acquisition programs (see Volume I, Appendix A for questionnaire and Volume II, Appendix A for responses) showed that:

- Development schedule growth, development cost growth, and production cost growth were not found to be directly related to the requirements for advances in performance, materials, or performance technologies.
- Munitions that had higher requirements for advances in production technology also tended to have higher percentage requirements for new test equipment and

tooling. Those munitions also tended to have advanced development, independent cost estimates and low-rate initial production releases associated with their acquisitions. The munitions with high production technology requirements that also had advanced development and independent cost estimates, had significantly lower development cost growth and development quantity growth than did munitions with lower production technology requirements but without advanced development or independent cost estimates. However, the sample size was not large enough or sufficiently stratified to determine whether any effects of high technology or resource risks may have been offset by the positive effects of those acquisition policies on development cost growth or development quantity growth. For similar reasons, it was not possible to separate out the effects on production cost growth of high technology and resource requirements from the effects of low-rate initial production.

In general, contractors had difficulty, even after the fact, in quantifying differences between their original program expectations and the actual outcomes in terms of the extent of the technology advance relative to the state-of-the-art. Yet these same contractors admitted, qualitatively, that several of their programs were pushing the state-of-the-art and, indeed, had suffered severe technical, cost, or schedule problems. This dichotomy points out the need for quantitative tools for assessing the technical state-of-the-art and for estimating full scale development (FSD) scheduling.

Two of the munitions (AGM-65D/F/G IIR Maverick and AGM-88A HARM) had large changes in the perceived nature of the threat during full scale development. However, there were no significant differences in any of the program outcome measures between the munitions with changing threats and the remainder of the munitions in the sample.

E. RECURRING PROBLEMS

Several pitfalls (major recurring problems) that affected the acquisition program outcomes were identified from the case studies in Volume II:

- Development requirements for munition modification programs were generally underestimated;
- Technological uncertainties were not adequately identified early in the development process;
- Design and production concepts were inadequately demonstrated and evaluated early in the development process;
- Producibility was not adequately considered in design decisions;

- Unrealistic test planning contributed to development schedule slippage and development cost growth;
- Larger overlaps between development and production greatly worsened the effects of unforeseen problems;
- Quantitative methods for estimating development schedules and development and production costs were generally inadequate, because their scope was inconsistent or incomplete, data bases and analogies were inappropriate, and important subsystems were not shown separately;
- Risks, schedules, costs, and test requirements and results were not consistently subjected to independent review.

F. RECOMMENDATIONS

Actions that could be taken to avoid the pitfalls identified above, and to improve the outcomes of future tactical munition acquisition programs, include:

- Requiring major munition modification programs to undergo the same milestone review process as new munitions, including an advanced development phase to identify and control performance and production risks;
- Developing and using technology trending models for identification of performance and production technological risks at the initiation of development;
- Reducing technological risks through advanced development prototyping and testing of critical subsystems and new production processes;
- Reducing production cost growth by requiring that producibility be demonstrated before approval of production release; restricting initial production rates to low levels until problems identified during early operational use can be corrected; and minimizing the extent of overlap between development and production;
- Developing and using more realistic schedule and cost-estimating models and procedures;
- Providing for an independent evaluation by OSD staff of program risks, schedules, costs, and test results, including consistent and full reporting in the SARs (or DAES), and use of checklists of critical questions at DAB reviews for new starts and major modification programs;
- Instituting a systematic effort to measure acquisition policy effectiveness with comparisons across a wide sample of acquisition programs, and documenting acquisition program histories to record lessons learned.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to the many individuals and organizations who contributed to this study. We would like to thank Mr. Robert Soule, Deputy Director, Program Assessment, in the Office of the Under Secretary of Defense (Acquisition), who served as cognizant official for the study.

The organizations that contributed information to the study include:

- Office of the Secretary of Defense
- U.S. Army
- U.S. Navy
- U.S. Air Force
- General Dynamics Corporation
- Hughes Aircraft Company
- Martin Marietta Corporation
- McDonnell Douglas Corporation
- Raytheon Company
- Rockwell International Corporation
- Texas Instruments, Incorporated.

We would also like to thank the reviewers, Mr. Stanley A. Horowitz, Dr. John E. Hove, and Dr. Richard E. Schwartz, for their comments. Ms. Janet Jones-Brooks provided exceptional secretarial support to the study and prepared the manuscript. Ms. Linda Garlet perceptively edited the document for publication.

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I. INTRODUCTION

During the past several decades, acquisition outcomes for tactical munitions programs have met with varying degrees of success in terms of accomplishing mission, schedule, and cost objectives. Although some programs have been successful, others have encountered serious problems, in spite of numerous policy changes and initiatives intended to improve the acquisition process. The differences in the outcomes of these programs provide an opportunity to investigate the reasons for program success. A better understanding of the causes of problems and the efficacy of acquisition program policies may point to the need for further policy changes.

A. OBJECTIVE

This paper examines the outcomes and lessons learned from selected tactical munitions programs. The objectives of this research were to:

- Investigate the nature, extent, and causes of recurring problems in these acquisition programs;
- Identify measures for program outcomes and collect data for each;
- Present policy recommendations for dealing with the problems observed;
- Compile a series of case studies that will provide a corporate memory of lessons learned;
- Provide a checklist of major issues and concerns for decisionmakers.

Acquisition outcomes were measured by comparing program schedule, cost, and quantity actuals to those planned at the time of the development estimate. We addressed these outcomes as indicators of management success; we did not undertake comprehensive examination of technical and performance measures relating to operational success.

B. APPROACH

A sample of nineteen contemporary tactical munitions was selected for analysis. The munitions, listed in Table I-1, were selected to represent different categories of munitions (air- and surface-launched intercept missiles, air- and surface-launched surface

attack missiles and rockets, and gun-launched guided projectiles), different service managers (Army, Navy, and Air Force) and varying degrees of success (including cancellation). Eight different companies were prime contractors.

Table I-1. Munitions Included in the Analysis

Designator	Name	New/ Mod	Management*	Users*	Prime	Second Source(s)
A/RIM-7E/H/J	Sparrow IIIB CW	Mod	N	AF, N, M, F	Raytheon	Foreign
AIM-7F	Sparrow III Pulse Doppler	Mod	N	AF, N, M, F	Raytheon	General Dynamics
A/RIM-7M	Sparrow III Monopulse	Mod	N	AF, N, M, F	Raytheon	General Dynamics
AIM-9L	Sidewinder	Mod	N	AF, N, M, F	Ford	Raytheon, Foreign
AIM-9M	Sidewinder	Mod	N	AF, N, M, F	Ford	Raytheon
AIM-54A	Phoenix	New	N	N, F	Hughes	
AIM-54C	Phoenix	Mod	N	N	Hughes	Raytheon
AIM-120A	AMRAAM	New	AF	AF, N, M, F	Hughes	Raytheon, Foreign
FIM-92A	Stinger-Basic	New	A	A, AF, M, F	General Dynamics	
FIM-92A	Stinger-POST/RMP	Mod	A	A, AF, M, F	General Dynamics	Raytheon, Foreign
AGM-65D/F/G	IIR Maverick	Mod	AF	AF, N, M, F	Hughes	Raytheon
A/R/UGM-84A/C/D	Harpoon	New	N	AF, N, F	McDonnell	
AGM-88A	HARM	New	N	AF, N, M, F	Texas Instruments	
AGM-114A/B	Hellfire	New	A	A, M, F	Rockwell, Martin	Rockwell, Martin
BGM-71A	TOW I	New	A	A, M, F	Hughes	Chrysler, Foreign
BGM-71D	TOW II	Mod	A	A, M, F	Hughes	Foreign
–	MLRS	New	A	A, F	LTV, FMC	Foreign
M-712	Copperhead CLGP	New	A	A, M, F	Martin	
–	5" Deadeye SALGP	New	N	N	Martin	

*A = Army
AF = Air Force
N = Navy
M = Marines
F = Foreign

In order to investigate the extent of any differences in acquisition program outcomes between new and modified munitions, the sample contains ten new munitions and nine modifications of existing munitions. Two of the new munitions (Harpoon and Hellfire) included minor modifications.

The sample is also spread over about 30 years. The AIM-7E Sparrow began engineering development in January 1960, and a modified version is still being produced three decades later. The AMRAAM began full scale development in December 1981. The sample is contemporary in that all but one of the munitions are either still in production or

in service, or are previous versions of munitions still in production or in service. One of the munitions (5" Deadeye SALGP) never entered production and was not deployed. Production has been completed for six of the munitions while the remaining twelve are still being produced. Timelines of the development and production phases for the munitions are shown in Figure I-1; bullets indicate the start of each phase. The figure does not show concurrency or gaps between the development and production phases. In actuality, several of the acquisition programs had overlaps between development and production phases, while other programs had gaps between phases.

For each of the munitions included in the sample, schedule dates, cost, and production quantity data, and narrative information were obtained from *Selected Acquisitions Reports* (SARs), the latest available editions of references [1, 2, and 3], and interviews with program management and contractor personnel. The SARs were used as the primary source of information because they are official government documents and are readily available.

Original estimates (generally as of Milestone II) of schedules, costs, and quantities were obtained from the earliest available SAR for each munition. Because some of the acquisition programs predate the initiation of SARs in 1967, their development estimates of schedules, costs, and quantities shown in this report may not have been the true original development estimates; they may instead be subsequent revisions. In addition, revised estimates of schedules, costs, and quantities were obtained from all of the year-end SARs following the first available SAR for each program. The December 1987 SAR was the latest available.

Using these data, calculations were made to show the extent of schedule and cost growth (or shrinkage in a few cases) for each program. Because production quantities have changed substantially since the original development estimates for most of the programs, and because these quantity changes affect cost changes, the extent of cost growth was measured by using the current estimate cumulative cost curve to calculate what the program cost would have been if the development estimate quantity had been produced.

To obtain information on technological risks and new resource requirements, IDA sent questionnaires to the prime contractors of the munitions in the sample. The questionnaire is reproduced in Appendix A. Responses were received from four of the prime contractors for eleven of the munitions in the sample.

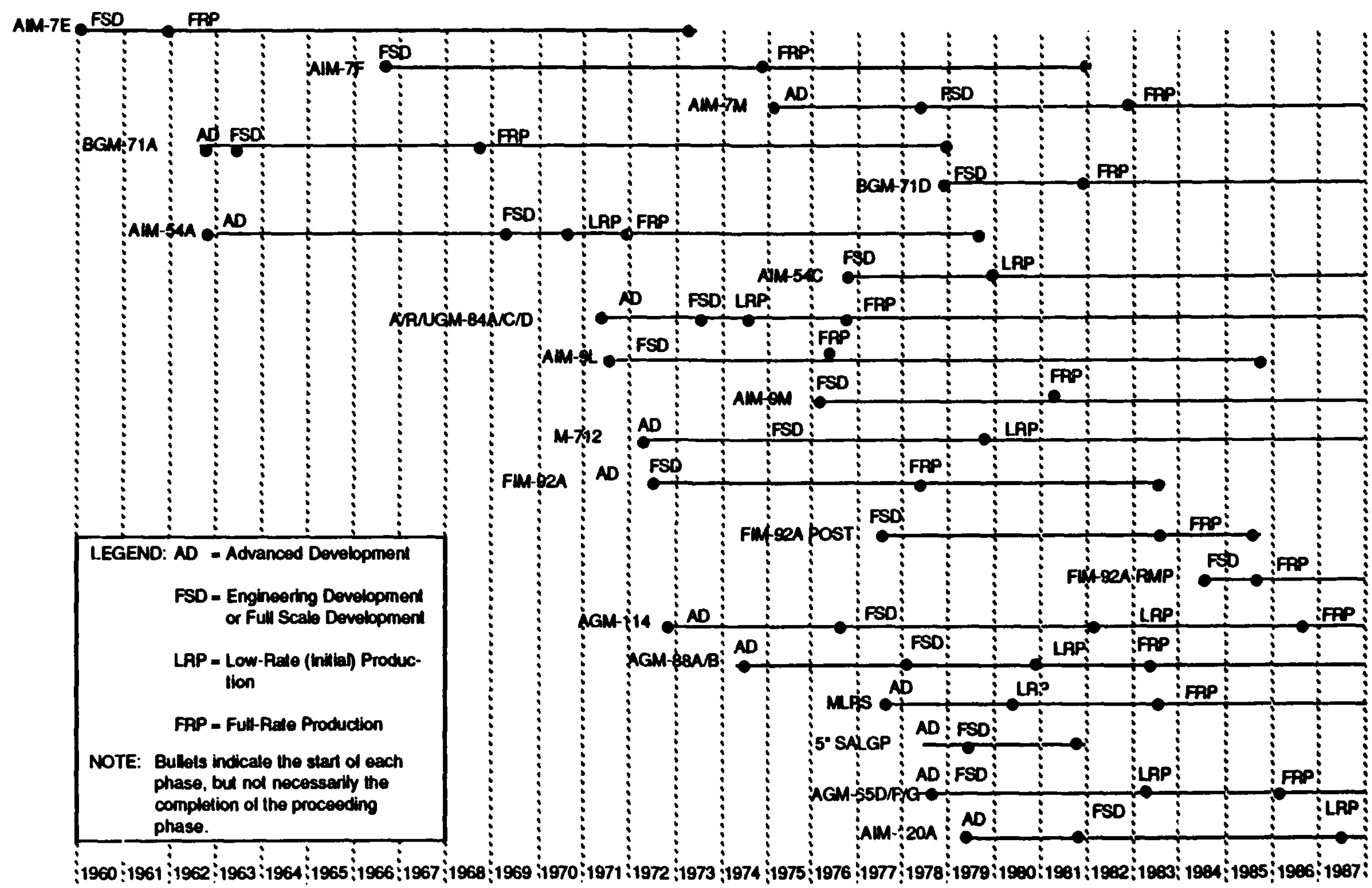


Figure I-1. Contract Timelines

In addition to the quantitative data, narrative information was obtained on the applicability of various defense acquisition policies and initiatives to the munitions. Information was also obtained where available concerning stability of the threat; the extent to which the performance and technical requirements were satisfied; the stability of development and production funding; and the nature, extent, and cause of major problems encountered and how they were managed. This narrative information and the quantitative data were used to prepare thirteen separate case studies for the nineteen munitions in the sample. These studies are contained in Volume II of this report. Those case studies contain the quantitative data and narrative information to support the conclusions and recommendations presented in this volume.

Volume I contains the results of a cross-section study of the differences in program outcome variables between the munitions in the sample. Non-parametric statistical methods were used in the analysis of the quantitative data. The distributions of the quantitative measures of program outcomes, resource requirements, funding stability, and concurrency were, in general, highly skewed and irregularly shaped. They were not normally distributed with bell-shaped frequencies, nor could they be easily transformed into the normal bell-shaped frequencies. The statistical significance of differences in a quantitative measure between categories of munitions characteristics, levels of technological risk, or applicability of various acquisition policies, was evaluated using Kruskal-Wallis and Mann-Whitney tests.

Spearman rank correlations and their levels of significance were used to measure the relationships between program outcomes, resource requirements, funding stability, and concurrency measures. Correlations of subsamples of these quantitative measures for particular categories of munitions characteristics, levels of technological risk, or applicability of various acquisition policies, were generally not evaluated because of the small numbers of munitions in each category. Correlations or differences which are stated to be significant in the text in this volume have a statistical significance level of 10 percent or less.

C. OUTLINE OF THE REPORT

This report addresses program outcomes and risks in the context of several acquisition strategies, program risks, and program characteristics. Figure I-2 shows the chapter where each category of data is analyzed. The arrows in Figure I-2 show which other categories of data are used in the analysis of a particular category. Basic program

characteristics, in terms of type of munition, the services and prime contractors responsible, whether or not the munition was new or a modification, and when the munition entered development and production were discussed in the preceding section.

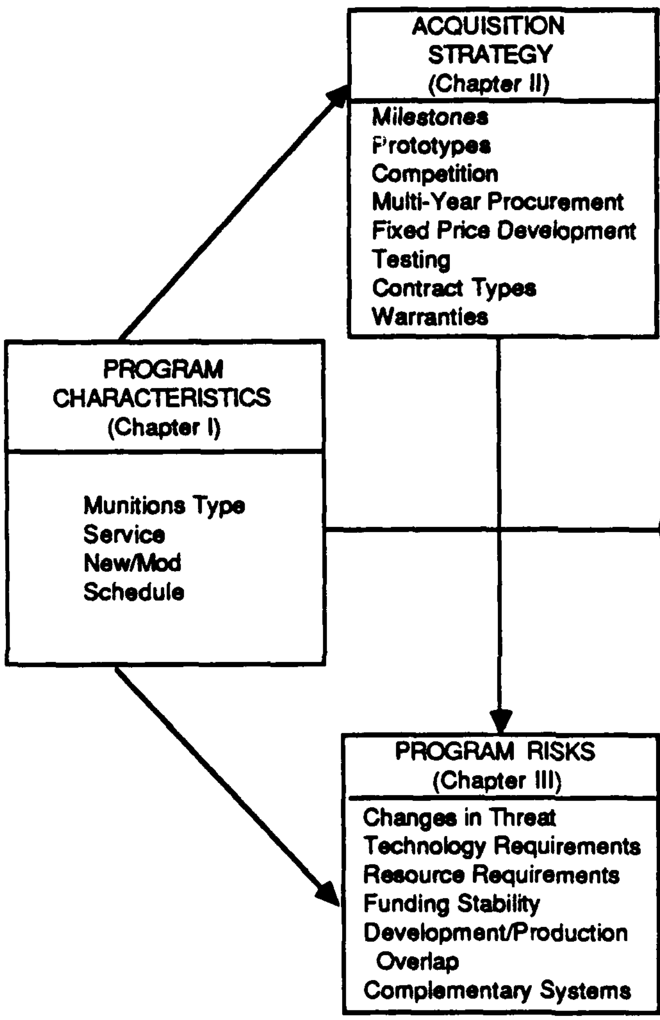


Figure I-2. Data Categories and Evaluation Relationships

Chapter II describes and compares the acquisition strategies for the munitions in the sample and relates them to program characteristics. Chapter III does the same for program risks. Relationships between program outcomes and acquisition strategies are analyzed in Chapter IV. Whether or not the program outcome measures are correlated to each other or when development or production started, or to resource requirements, or to the measures of funding stability or the overlap between development and production is also reported in Chapter IV. Significant differences between munitions to which a particular acquisition

policy was applied and the other munitions are reported in Chapter IV. Similar evaluations are shown in Chapter IV for subsamples categorized by munitions characteristics, levels of technological risk, and whether or not the design requirements were satisfied. Conclusions, in terms of lessons learned, and recommendations to assist in identifying and managing potential acquisition problems are contained in Chapter V. The statistical analyses and supporting data for those analyses and for the figures and tables in the text, are documented in the Notes following Chapter V.

The second volume of this report consists of thirteen separate case studies covering the nineteen munitions included in the sample. Each case study contains a program description, covering the mission, history, and acquisition strategy; a system technical description, covering the munition subsystems, performance and technical requirements and test results; a program cost/schedule assessment covering cost/schedule estimates, program funding, and cost/quantity relationships; and lessons learned, in terms of the threat, requirements, technology, acquisition policy, and political environment.

D. RELATED WORK

During the course of our work, we reviewed related research in the field [4 through 43]. We found our findings agreed with previous research in some cases and disagreed in others.

Our findings agree with some of the reasons for program success identified in [4 and 5], and our recommendations are consistent with recommendations in those works and in [6 and 7]. In particular, the importance of identifying and controlling technological risks, and the findings on the adverse effects of poor cost estimating, as cited in those references, are fully supported here. Our work supports the recommendations made in [8] for identifying technological risks by quantifying technological trends over time. Our analyses also support the recommendations made over thirty years ago in [9] for reducing technological risks through advanced development and prototyping.

Problems of producibility cited in [6] were identified from an examination of six weapons, of which two (HARM and Copperhead) are included in our sample. Many of the same problems can be seen in munitions in our sample that were not considered in [6]. The same recommendations for demonstrating producibility during development are made here.

On the other hand, our analysis does not include some of the other reasons for program success identified in [4, 5, 6, and 7]. We did not directly consider quality of

program management or the contractor office and technical staffs, as did [4 and 5], although inferences can be drawn from the acquisition program outcome measures evaluated here. Nor do our results show that stability of requirements and funding are major reasons for program success, as cited in [4, 5, 6, and 7].

This report is the latest in a series of projects at IDA that compared schedule and cost outcomes of a number of weapons. Those earlier projects [10 and 11] examined a wider variety and number of weapons than reported on here, and their findings and recommendations are similar to ours. This report is based on a more detailed examination of fewer munitions and uses more recent data than were available for [10 and 11].

II. THE ACQUISITION ENVIRONMENT AND STRATEGY

This chapter compares how defense acquisition policies and initiatives were applied to the munitions in the sample. To provide a context for these comparisons, the chapter opens with a brief description of the existing acquisition milestone process and how it has evolved since 1960.

A. DEFENSE ACQUISITION MILESTONES

The purposes of the defense acquisition milestone process are:

- To evaluate the progress of an acquisition program at specific milestones;
- To ensure that appropriate requirements are met at each milestone before the acquisition program is allowed to proceed.

The phases of the process according to Department of Defense (DoD) Directive 5000.1 and DoD Instruction 5000.2 (dated March 12, 1986), are displayed in Figure II-1. The figure also presents information about documentation and the activities that must be accomplished before each milestone review.

The milestone dates and initial operational capability (IOC) dates of the munitions in our sample are shown in Table II-1. These dates are the latest estimates from the SARs for the different munitions, as summarized in the case studies in Volume II. Where no milestone dates are shown, either the acquisition phase of the program predated the definition and establishment of a required reporting milestone, or the milestone dates were not recorded completely in the SARs. The SARs themselves were established in 1967, and Milestones I (Concept Selection), II (Program Go-ahead), and III (Production Approval) were established in 1970 to allow the Office of the Secretary of Defense/Director of Defense Research and Engineering (OSD/DDR&E) to monitor major programs at specific major decision points. Detailed program direction and management was to be provided by the services, and a Development Concept Paper (DCP) was to serve as a contract between OSD/DDR&E and the service. By that time, some of the munitions in the sample had already begun advanced development or full scale (engineering) development.

Acquisition Milestones		0 Mission Need Determination		I Concept Selection		II Program Go-Ahead		IIIA Production Release		IIIB Full-Rate Production
Acquisition Phase	Mission Feasibility		Concept Exploration (Competitive Contractor Studies)		Demonstration and Validation (Competitive Efforts by Contractors)		Full Scale Development (1 or 2 Prime Contractor(s) and Subcontractors)		Production and Deployment (1 or 2 Prime Contractor(s) and Subcontractors)	
Decision Documentation		PDM JMSNS With Service POM	Develop Acquisition Strategy	SDDM • SCP • TEMP Prepare SCP/TEMP	Execute and Modify Acquisition Strategy	SDDM • DCP/IPS • TEMP Prepare DCP/IPS and Update TEMP	Execute and Modify Acquisition Strategy	Service Decision Prepare Service Documentation	Execute and Modify Acquisition Strategy	
Activities	- Technology Advancement - LCC Assessment - Mission Feasibility and Utility Analysis		- Proposal Review and Contractor Selection - System Requirements Review - Trade Studies - Mission Requirements - System Requirements Definition/ Specification - Requirement Allocation - Operational Concept Trades - Systems Functional Concept Trades - Technology/Risk Assessment - Interface Definition - LCC Assessment - Logistics Supportability - Functional Baseline - Development		- Proposal Review and Contractor Selection - System Requirements Review - Trade Studies - System Allocated Baseline Definition and Element Specifications - Performance/Cost/Schedule Refinement - Update LCC - Logistics Support Validation - Interface Agreements and Specifications - System Integration Plans - Configuration Management Program Defined - Risk Planning/Management - Production Capability Assessment - PEP - Development/Operational Testing Coordination Assessment - System Design Review - SEMP Preparation		- Proposal Review and Contractor Selection - Test and Evaluation - SEMP Implementation - Program Documentation Update - FCA/FQR - Configuration Management - Human Factor/Training Plans - Refine LCC Estimate - Design Reviews - ILS Planning and Implementation - Production Readiness Reviews - Developmental/Operational Testing Coordination Assessment - Product Baseline Development - PEP		- Proposal Review and Contractor Selection - Initial Production - Physical Configuration Audit - Full Production - Update PEP - Product Engineering Completed - Full-Scale ILS Implemented - Technical Data Package - Support Deployment - Plan Life Extension Program - Change Management - Repair Program - Field Support Program - Disposal Planning - Operations and Maintenance	

Terms

DCP/IPS	- Decision Coordinating Paper/Integrated Program Summary
FCA	- Functional Configuration Audit
FQR	- Formal Qualifications Review
ILS	- Integrated Logistics Support
JMSNS	- Justification for Major System New Start
LCC	- Life-Cycle Cost
PDM	- Program Decision Memorandum
PEP	- Producibility Engineering and Planning
POM	- Program Objectives Memorandum
SCP	- System Concept Paper
SDDM	- Secretary of Defense Decision Memorandum
SEMP	- System Engineering Master Plan
TEMP	- Test and Evaluation Master Plan

Source: ASG/DSMC

Figure II-1. Defense Acquisition Process Phases (Prior to 1988)

Table II-1. Milestone and Initial Operational Capability Dates

Designator	Weapon	MS-0	MS-I	MS-II	MS-IIIA	MS-IIIB/III	IOC	Production Completion
AIM/RIM-7E/H/J	Sparrow IIIB CW	N.A.	N.A.	1/60	N.A.	N.A.	12/63	12/73
AIM-7F	Sparrow III Pulse Doppler	N.A.	N.A.	12/65	None	I.U.	4/76	FY 81
AIM/RIM-7M	Sparrow III Monopulse	N.A.	I.U.	4/78	I.U.	11/82	1/83	FY 89
AIM-9L	Sidewinder	N.A.	None	8/71	None	12/80	5/78	FY 85
AIM-9M	Sidewinder	N.A.	None	2/76	2/78	2/81	9/82	FY 92
AIM-54A	Phoenix	N.A.	12/62	N.A.	N.A.	I.U.	12/73	FY 79
AIM-54C	Phoenix	N.A.	None	10/76	N.A.	5/88	12/86	FY 91
AIM-120A	AMRAAM	10/75	11/78	11/82	6/87	3/89	10/89	FY 97
FIM-92A	Stinger-Basic	N.A.	N.A.	5/72	N.A.	11/77	2/81	FY 83
FIM-92A	Stinger-POST/RMP	N.A.	None	I.U.	I.U.	I.U.	I.U.	FY 93
AGM-65D/F/G	IIR Maverick	N.A.	11/73	9/76	3/82	9/82	2/86	FY 97
A/R/UGM-84A/C/D	Harpoon	N.A.	3/70	3/74	6/75	I.U.	A8/79 R7/77 U7/77	FY 92
AGM-88A	HARM	N.A.	10/72	2/78	N.A.	3/83	11/83	FY 91
AGM-114A/B	Hellfire	12/72	None	2/76	1/82	3/82	7/86	FY 93
BGM-71A	TOW I	N.A.	N.A.	I.U.	None	I.U.	9/70	FY 82
BGM-71D	TOW II	N.A.	I.U.	9/78	None	9/81	10/83	FY 92
–	MLRS	I.U.	1/77	Omitted	I.U.	5/80	3/83	FY 92
M-712	Copperhead CLGP	None	None	6/75	11/79	N.A.	12/82	FY 88
–	5" Deadeye SALGP	None	None	11/77	N.A.	Cancelled	N.A.	N.A.

N.A. = Not Applicable.
I.U. = Information unavailable.

In 1975, the service secretaries were given authority for production decisions made after Milestone III. In 1979, Milestone III was separated the Milestones IIIA and IIIB, as shown in Figure II-1. This change occurred after most of the munitions in the sample had entered production. Milestone 0 (Mission Need Determination) was established after most of the munitions in the sample had entered concept exploration or a later acquisition phase. Milestones IV (Logistics Readiness Review) and V (Major Upgrade Decision) were established in September 1987, but have not been applied to any of the munitions in the sample.

The reason no Milestone II dates are given for the AIM-54A Phoenix, Milestone IIIA or IIIB dates for AIM/RIM-7E/H/J Sparrow, or Milestone IIIA dates for AIM-54A and AIM-54C Phoenix and HARM is because the milestones were established too late to be applicable to those programs. The reason that there were no Milestone IIIA dates for AIM-7F Sparrow, AIM-9L Sidewinder, TOW I, or TOW II is that there were no separate low-rate initial production phases for those programs.

Two anomalies can be observed in Table II-1. The first is that most of the munition modification programs in the sample were allowed to proceed to Milestone II (Program Go-ahead) without a Milestone I decision to identify and eliminate significant performance, production, schedule, and cost uncertainties.

The second anomaly is the missing Milestone III dates for AIM-7F Sparrow and Harpoon, and the missing Milestone IIIA date for AIM/RIM-7M Sparrow. These missing dates can only be explained by either: (1) incomplete recording in the SARs, or (2) the milestone decisions never took place.

B. ACQUISITION STRATEGY

According to OMB Circular A-109, which governs major acquisitions, an acquisition strategy should be developed "as soon as the agency decides to solicit alternative system design concepts that could lead to the acquisition of a new major system." The elements to be considered in developing an acquisition strategy can be put into three categories:

- Strategic concerns, including national objectives, the threat, operational requirements, the technology base, overall program objectives, market factors, and the critical program issues;
- Technical concerns, specifically relating to design, test and evaluation, production, and deployment;

- Resource concerns, including personnel/organization, schedule, business/financial, management information, and facilities.

For elements critical to the success of the program, alternatives and decision time intervals (windows) must be selected that meet program objectives. These alternatives and windows together constitute the acquisition strategy. A contemporary acquisition strategy would include:

- Estimates for cost, schedule, and performance during the entire process;
- A contracting plan that includes plans for competition;
- An assessment of the type of warranties that will be sought;
- Plans and criteria for source selection at each stage;
- Funding plans;
- Plans for testing and evaluation, possibly including prototypes;
- Plans for development and allocation of appropriate logistics support;
- An assessment of program risks.

It is not possible to reconstruct, exactly and totally, the acquisition strategy for each of the munitions in the sample. All that is available is information showing whether or not certain policies were incorporated into the acquisition strategy for each munition. In the following sections of this chapter, each munition is characterized in terms of the different acquisition policies and initiatives applied during each phase of the acquisition process.

One of the important distinctions among the munitions in the sample concerns the extent of competition, which has become more important with the various DoD competitive initiatives and the Competition in Contracting Act. The level of competition can vary from none at all (sole source), to competition over design and price during the development phases, to competition over price only during the production phases. The applicability of these different levels of competition to the munitions in the sample is shown in Figure II-2.

C. ACQUISITION POLICIES DURING ADVANCED DEVELOPMENT

Application of selected acquisition policies and initiatives during the demonstration and validation phase (also referred to as "advanced development") are shown in Table II-2 for each of the munitions in the sample.

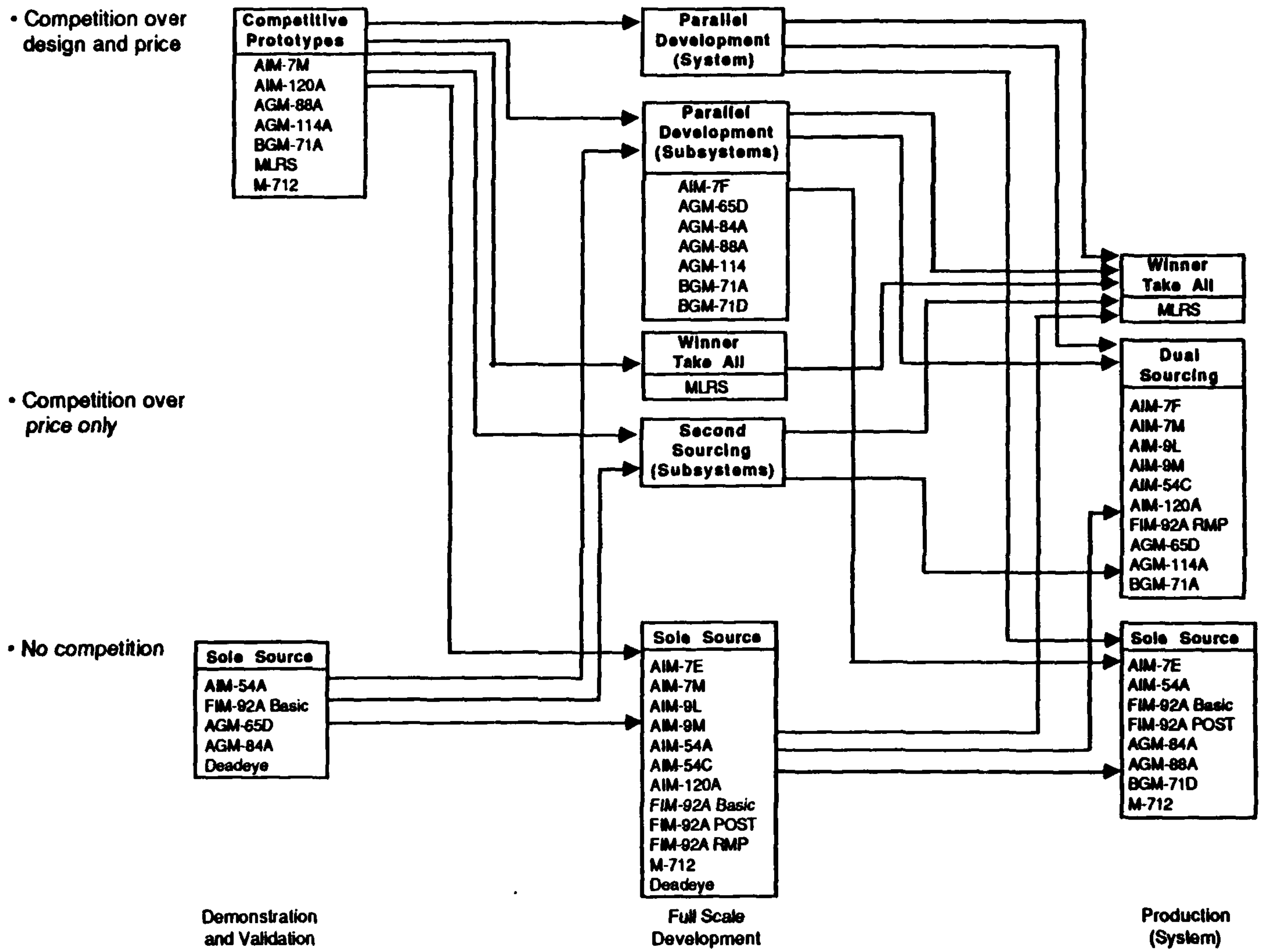


Figure II-2. Types of Competition

Table II-2. Advanced Development Start Dates and Acquisition Policies Applied During Advanced Development

Designator	Title	New/Mod	Entered AD	Competition	Prototypes	
					Whole System	Subsystem
A/RIM-7E	Sparrow III B CW	Mod	N.A.			
AIM-7F	Sparrow III Pulse Doppler	Mod	N.A.			
A/RIM-7M	Sparrow III Monopulse	Mod	1/75	Yes	No	Yes
AIM-9L	Sidewinder	Mod	N.A.			
AIM-9M	Sidewinder	Mod	N.A.			
AIM-54A	Phoenix	New	12/62	No	Yes	No
AIM-54C	Phoenix	Mod	N.A.			
AIM-120A	AMRAAM	New	2/79	Yes	Yes	No
FIM-92A	Stinger-Basic	New	I.U.	No	No	I.U.
FIM-92A	Stinger-POST/RMP	Mod	N.A.			
AGM-65D/F/G	IIR Maverick	Mod	I.U.	No	No	Yes
A/R/UGM -84A/C/D	Harpoon	New	6/71	No	Yes	I.U.
AGM-88A	HARM	New	5/74	Yes	Yes	Yes
AGM-114A/B	Hellfire	New	12/72	Yes	Yes	No
BGM-71A	TOW I	New	10/62	Yes	Yes	No
BGM-71D	TOW II	Mod	N.A.			
–	MLRS	New	9/77	Yes	Yes	No
M-712	Copperhead CLGP	New	2/72	Yes	Yes	No
–	5" Deadeye SALGP	New	I.U.	No	No	No

N.A. - Not applicable.
I.U. - Information unavailable.

Of the nine modification programs, only the AIM/RIM-7M Monopulse and the IIR Maverick programs had advanced development phases, but the advanced development contract dates for the IIR Maverick are not readily available, and no Milestone I dates are shown in the SAR for either munition.

All of the new munitions in the sample had advanced development phases. However, for the Basic Stinger and the 5" Deadeye SALGP, the advanced development contract dates are not readily available, and no Milestone I dates are shown in the SARs.

Of the nine munitions for which the dates of entering advanced development could be determined, the six that entered advanced development after 1971 all had competition during the advanced development phase. All of these nine had either whole system or subsystem prototypes, regardless of when they entered advanced development.

Of the ten new programs, six were competitive during the advanced development phase, and all six of those plus two non-competitive programs had whole system prototypes. There is not enough evidence to establish any relationship between prototyping and competition; however, program managers and contractors for the new munitions that underwent competition seemed to realize the value of prototyping.

Of the two modification programs that underwent advanced development, one was competitive, and neither had whole system prototypes, but both had subsystem prototypes.

There were no clear relationships between whether or not the program had an advanced development phase and:

- The program manager;
- The prime contractor;
- The type of munition.

D. ACQUISITION POLICIES DURING FULL SCALE DEVELOPMENT

Application of selected acquisition policies during the full scale development phase are shown in Table II-3. Limited data are shown for the MLRS, which had a tailored acquisition program that proceeded directly from prototype construction and testing to low-rate initial production without a full scale development phase.

Although none of the munitions in the sample had competition at the system level during full scale development, four had competition at the subsystem level. Eight different

Table II-3. Full Scale Development Start Dates and Acquisition Policies Applied During Full Scale Development

Designator	Title	Entered FSD	Competition		Contract Type	Independent	
			System	Subsystem		Test	Cost Estimate
A/RIM-7E	Sparrow III B CW	1/60	No	No	CPIF	No	No
AIM-7F	Sparrow III Pulse Doppler	7/66	No	No	CPIF	No	No
A/RIM-7M	Sparrow III Monopulse	4/78	No	No	FPI	No	No
AIM-9L	Sidewinder	8/71	No	No	CPFF/CPIF	No	No
AIM-9M	Sidewinder	2/76	No	No	CPFF	No	No
AIM-54A	Phoenix	4/69	No	No	CPFF	Yes	I.U.
AIM-54C	Phoenix	10/76	No	No	CPAF	No	No
AIM-120A	AMRAAM	12/81	No	No	FPI/FFP	No	Yes
FIM-92A	Stinger-Basic	6/72	No	No	I.U.	I.U.	I.U.
FIM-92A	Stinger-POST/RMP	6/77	No	No	CPIF/FFP	I.U.	I.U.
AGM-65D/F/G	IIR Maverick	10/78	No	Yes	CPIF	Yes	Yes
A/R/UGM -84A/C/D	Harpoon	6/73	No	Yes	CPIF	No	No
AGM-88A	HARM	2/78	No	No	CPIF	Yes	Yes
AGM-114A/B	Hellfire	10/76	No	Yes	CPIF	No	Yes
BGM-71A	TOW I	6/63	No	Yes	CPFF	No	No
BGM-71D	TOW II	12/78	No	No	CPFF/FPE	No	No
–	MLRS	N.A.	N.A.	N.A.	CPIF/CPFF	No	No
M-712	Copperhead CLGP	7/75	No	No	CPFF	No	Yes
–	5" Deadeye SALGP	8/78	No	No	CPIF	No	Yes

N.A. - Not applicable.
I.U. - Information unavailable.
CPFF - Cost plus fixed fee.
CPAF - Cost plus award fee.
CPIF - Cost plus incentive fee.
FFP - Firm fixed price.
FPE - Fixed price with escalation.
FPI - Fixed price incentive.

combinations of contract types were used. Only three of the munitions were subjected to independent tests, while six had independent cost estimates. The type (or combination of types) of contract(s) and whether or not there was competition at the subsystem level, independent testing, or independent cost estimates are not related to when the munitions entered full scale development. Further, there were no clear relationships among the various acquisition policies applied.

There are, however, clear relationships between three of the acquisition policies applied and whether or not there was an advanced development phase. Of the seven munitions (all modifications) that did *not* have advanced development, none had competition at the subsystem level, independent testing, or independent cost estimates. Of the twelve munitions that did have advanced development, (ten new and two modified), four had competition at the subsystem level, three had independent testing, and six had independent cost estimates. It appears that munitions that underwent advanced development were more likely to have competition at the subsystem level, independent testing, and independent cost estimates.[1]

There were no clear relationships between the application of any of the acquisition policies during full scale development and:

- The program manager;
- The prime contractor;
- The type of munition.

E. ACQUISITION POLICIES DURING PRODUCTION

Application of selected acquisition policies during the production phase are shown in Table II-4 for each of the munitions in the sample. No data are shown for the 5" Deadeye SALGP, which was cancelled just before it was due to enter production. Further, although whole system competition is shown in Table II-4 for the MLRS, that was a "winner take all" competition, which was decided at the completion of advanced development.

Nine of the munitions in the sample had low-rate production prior to entering full-rate production. Two of the munitions (AIM-54C Phoenix and AMRAAM) have still not entered full-rate production. Twelve of the munitions in the sample have had, or will have, production competition at the system level, and ten had production competition at the

Table II-4. Production Start Dates and Acquisition Policies Applied During Production

Designator	Title	Entered		Competition		Contact Type	Multi-Year Contract	Warranty		Foreign Production
		Low-Rate Production	Full-Rate Production	Whole System	Sub-System			Whole System	Sub-System	
A/RIM-7E	Sparrow III B CW	N.A.	1/62	No	No	FFP/FPI	No	No	No	Yes
AIM-7F	Sparrow III Pulse Doppler	N.A.	10/74	Yes	Yes	FFP/FPI	No	Yes	No	No
A/RIM-7M	Sparrow III Monopulse	I.U.	12/82	Yes	Yes	FFP/FPI	No	Yes	No	No
AIM-9L	Sidewinder	N.A.	4/76	Yes	Yes	CPIF/FFP	No	I.U.	I.U.	Yes
AIM-9M	Sidewinder	I.U.	2/81	Yes	Yes	FFP	No	No	Yes	No
AIM-54A	Phoenix	11/70	12/71	No	No	FFP/FPI	No	No	No	No
AIM-54C	Phoenix	12/79	10/90*	Yes*	Yes	FFP/FPI	No	Yes	No	No
AIM-120A	AMRAAM	10/87	N.A.	Yes	No	FFP/FPI	No	No	I.U.	Yes
FIM-92A	Stinger-Basic	N.A.	4/78	No	No	FPI	No	No	No	Yes
FIM-92A	Stinger-POST/RMP	N.A.	9/83	Yes	Yes	FPI/FFP	Yes	No	Yes	No
AGM-65D/F/G	IIR Maverick	4/83	3/86	Yes	Yes	FPI/FFP	No	Yes	No	No
A/R/UGM -84A/C/D	Harpoon	7/74	11/76	No	No	FFP/FPI	No	No	No	No
AGM-88A	HARM	11/80	3/83	Yes*	Yes	CPFF/FPI/FFP	No	Yes	Yes	No
AGM-114A/B	Hellfire	3/82	7/86	Yes	Yes	FPI/FFP	No	I.U.	I.U.	No
BGM-71A	TOW I	N.A.	11/68	Yes	No	CPAF/FFP/FPI/FPE	Yes	No	No	Yes
BGM-71D	TOW II	N.A.	12/81	No	Yes	FFP/FPE	Yes	No	No	Yes
–	MLRS	5/80	9/83	Yes	I.U.	CPIF/FPI/FFP	Yes	No	No	Yes
M-712	Copperhead CLGP	11/79	N.A.	No	No	CPIF/FFP	Yes	Yes	No	No
–	5" Deadeye SALGP	Cancelled	Cancelled	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	No

N.A. - Not applicable.
I.U. - Information unavailable.
CPFF - Cost plus fixed fee.
CPAF - Cost plus award fee.
CPIF - Cost plus incentive fee.
FFP - Firm fixed price.
FPE - Fixed price with escalation.
FPI - Fixed price incentive.
*Projected

subsystem level. Eight different combinations of contract types were used. Five of the munitions have had, or will have, multi-year production contracts, and seven have had, or will have, foreign production. There are warranties at the system level for three of the munitions and at the subsystem level for seven of the munitions.

With the exception of competition at the subsystem level, none of the acquisition policies seem to be related to when production began. Munitions that entered production later in the period covered by the sample were much more likely to have production competition at the subsystem level than were munitions that entered production earlier.[2]

Only one clear relationship was found among the various acquisition policies applied during production. The relationship between production competition at the system and subsystem levels is shown in Table II-5. Whether or not there was production competition at the system level appears to be closely related to whether or not there was production competition at the subsystem level.[3]

Table II-5. Relationship Between Production Competition at the System and Subsystem Levels

		System Competition		
		Yes	No	Total
Subsystem Competition	Yes	9	1	10
	No	2	5	7
	Insufficient Information	1	0	1
	Total	12	6	18

Whether or not the system is new or modified does not have any clear relationship to the type of production contract, or whether or not there were multi-year contract, system or subsystem warranties, or foreign production. However, there are clear relationships between whether the munition was new or modified and whether or not there was subsystem competition and low-rate production before entering full-rate production.[4] Seven of the nine new munitions that entered production had an initial low-rate production period, in contrast to only two of the eight modified munitions for which data were available. Eight of the nine modified munitions had production competition at the

subsystem level, in contrast to two of the eight new munitions for which data were available.

With the exception of multi-year contracting, there were no clear relationships between application of any of the acquisition policies and:

- The program manager;
- The prime contractor;
- The type of munition.

There were clear relationships between multi-year contracting, which service is prime manager, and the type of munition.[5] Five of the seven Army munitions that entered production had multi-year contracts, in contrast to none of the nine Navy munitions and neither of the two Air Force munitions. None of the eight air-launched intercept missiles (AIM designators) and none of the four air-launched surface attack missiles (AGM designators) that entered production had multi-year contracts, in contrast to five of the six other munitions in the sample.

III. COMPARISONS OF ACQUISITION PROGRAM RISKS

In the previous chapter, the nineteen munitions in the sample were compared in terms of the application of different major acquisition policies that were introduced since 1960. In this chapter, the nineteen munitions are compared in terms of the various risks that were faced during acquisition. The specific risks included in the comparisons are:

- Changes in the threat;
- Extent of technology change required to meet performance and production requirements;
- Extent of requirements for new resources;
- Stability of funding;
- Extent of overlap between development and production;
- Availability of required complementary systems such as platforms or target designators.

A. CHANGES IN THE THREAT

Changes in the threat to be combatted by a munition affect the acquisition program for that munition in two possible ways: changes in performance requirements and changes in the quantity to be acquired. Changes in the quantity requirements can result from changes in the numbers of targets or from choices between munitions based upon budget availability and differences in cost and performance. However, the selected acquisition reports (SARs) do not always show the specific reasons for all of the program quantity changes. For successful acquisitions, the program quantities tend to increase beyond the numbers initially projected, as will be shown in the next chapter.

Changing performance requirements during FSD occurred for two of the nineteen munitions in the sample: IIR Maverick and HARM. Performance requirements for the imaging infra-red (IIR) seeker for the Maverick were changed as a result of intelligence information on the levels of contrast between potential targets in potential target environments. Performance requirements for the HARM were changed substantially as a result of intelligence information on the emission characteristics of potential targets. The

extent of any increase in development costs or delay in the development schedule due to changes in performance requirements cannot always be separated in the SARs from other changes in development costs or schedules.

Both the IIR Maverick and HARM programs included many of the acquisition policies described in Chapter II. Both had advanced development phases in which either system or subsystem prototypes were produced. The advanced development phase was competitive for one of the munitions (HARM), but full scale development was not competitive for either. Both of these munitions had independent testing, independent cost estimates, low-rate initial production phases, competition during production at both the system (projected for the HARM) and subsystem levels, and system warranties.[1] The HARM also had warranties at the subsystem level. This pattern differed from the application of the acquisition policies to the other munitions in the sample in that:

- Only one of the other munitions was subjected to independent testing;
- Only four of the other munitions had independent cost estimates;
- Only four of the other munitions had system warranties.

B. REQUIREMENTS FOR ADVANCES IN TECHNOLOGY

The prime contractors for eleven of the munitions in the sample provided information on the expected level of technical advance required at the time the development program was initiated, and the actual level of technical advance required to complete the development program. This analysis was restricted to the munitions' guidance subsystems because:

- The guidance system was usually responsible for the largest subsystem development costs,
- Many of the other subsystems involve numerous subcontractors from whom data could be obtained only with a much larger expenditure of time and effort than was available for this project.

Each of the contractors for the eleven munitions submitted data in reply to a questionnaire on the level of technological advance required to meet performance and technical requirements and the extent of usage of new or unfamiliar (to the contractor) materials and new or unfamiliar production processes. For each of these three measures of technical advances, the contractors submitted responses showing whether the requirement was satisfied by:

- Off-the-shelf technology;
- Minor technological changes (less than 10 percent);
- Substantial technological changes (between 11 percent and 50 percent);
- Extensive technological changes (greater than 50 percent);
- All new technology.

All new technology, in terms of performance, materials, or production processes, was required for none of the eleven munitions for which responses were obtained.

The questionnaire used to obtain this information is reproduced in Appendix A. The responses to the questionnaire are contained in Volume II. Because the responses are proprietary, the data presented here are aggregated so as to be unidentifiable as to contractor or munition.

The required levels of advance in technology do not show any particular pattern over time when the munitions are arranged chronologically according to full scale development start date. The chronology is shown in Figure III-1.

Requirements for advances in performance, materials, or production processes were not significantly related to munition categories.[2] Differences between the required levels of advance in technology and munition categories are shown in Table III-1.

Even though five of the seven new munitions required extensive advances in performance, in contrast to one of the four modified munitions, the difference is not statistically significant. Substantial or extensive advances in production process technology were required by all seven of the new munitions, but by only two of the four modified munitions; this difference is not quite statistically significant.

Advances in performance did not always require comparable advances in materials or production technologies for the munitions in the sample.[3] However, the levels of required advances in materials and production technologies were the same for six of the new munitions but for only one of the modified munitions, as shown in Table III-2. This result for new munitions should not be surprising. Advances in materials technology for new munitions generally require advances in production processes. For modified munitions, there is more likely to have already been some experience with either the materials or production technologies to be used.

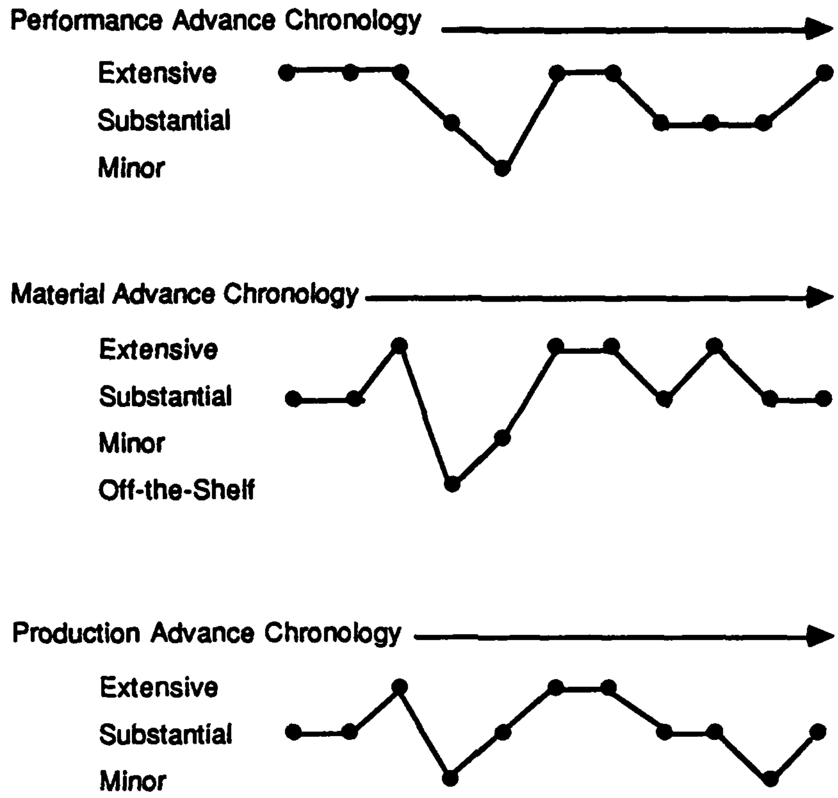


Figure III-1. Required Advance in Technology in Chronological Order of the Start of Full Scale Development

Whether or not certain of the acquisition policy initiatives were applied was related to the extent of technological advance required for the munitions in the sample.[4] The numbers of munitions at each level of required technological advance to which the acquisition policy initiatives were applied are shown in Table III-3.

Advanced development was used as a means for alleviating problems of technological advancement for most of the munitions in the sample. Five of the six munitions with extensive requirements for advances in performance underwent an advanced development phase. Four of those five had competitive advanced development phases and prototypes. Seven of the nine munitions that had either substantial or extensive requirements for advances in materials, and eight of the nine munitions that had either substantial or extensive requirements for advances in production process technologies also had advanced development phases. Those munitions with substantial or extensive requirements for advances in production technologies were significantly more likely to have

had advanced development phases than were munitions with lesser requirements for advances in production technologies.[5]

Table III-1. Differences Between Program Characteristics and Requirements for Advances in Technology

	Off-the-Shelf	Minor	Substantial	Extensive	Total
Performance					
Intercept	0	0	1	4	5
Surface Attack	0	1	3	2	6
Material					
Intercept	1	0	3	1	5
Surface Attack	0	1	2	3	6
Production Process					
Intercept	0	1	3	1	5
Surface Attack	0	1	3	2	6
Performance					
Air Launch	0	1	2	3	6
Surface Launch	0	0	2	3	5
Material					
Air Launch	1	1	2	2	6
Surface Launch	0	0	3	2	5
Production Process					
Air Launch	0	1	4	1	6
Surface Launch	0	1	2	2	5
Performance					
Army	0	1	1	3	5
Navy	0	0	2	2	4
Air Force	0	0	1	1	2
Material					
Army	0	1	2	2	5
Navy	1	0	2	1	4
Air Force	0	0	1	1	2
Production Process					
Army	0	1	2	2	5
Navy	0	1	2	1	4
Air Force	0	0	2	0	2
Performance					
New	0	1	1	5	7
Modification	0	0	3	1	4
Material					
New	0	1	4	2	7
Modification	1	0	1	2	4
Production Process					
New	0	0	5	2	7
Modification	0	2	1	1	4

Table III-2. Numbers of Munitions for Each Level of Required Material and Production Technology

New						
Materials \ Production	Off-the-Shelf	Minor	Substantial	Extensive	All New	Total
Off-the-Shelf						
Minor			1			1
Substantial			4			4
Extensive				2		2
All New						
Total			5	2		7

Modified						
Materials \ Production	Off-the-Shelf	Minor	Substantial	Extensive	All New	Total
Off-the-Shelf		1				1
Minor						
Substantial		1				1
Extensive			1	1		2
All New						
Total		2	1	1		4

Competition was generally not used as a means of providing alternative solutions to problems of technological advancement during full scale development. None of the munitions had competition at the systems level during engineering development, regardless of the extent of required advances in technology. The extent of competition at the subsystem level during engineering development was not much greater.

Munitions with substantial or extensive requirements for advances in technology were less likely to have had independent testing. However, independent cost estimates were used in attempting to control the costs associated with technological advancement. Those munitions with substantial or extensive requirements for advances in production technologies were significantly more likely to have had independent cost estimates than were munitions with lesser requirements for advances in production technologies.[6]

Low-rate initial production phases were also used in attempting to control the costs associated with technological advancement. This was true for six of the nine munitions with substantial or extensive advances in performance, five of the eight with substantial or

extensive advances in materials technology, and six of the eight with substantial or extensive advances in production technology.

Table III-3. Numbers of Munitions for Which Selected Acquisition Policies Were Applied at Each Required Level of Technological Advance

	Off-the-Shelf	Minor	Substantial	Extensive
Advanced Development				
Performance	0/0	1/1	2/4	5/6
Materials	0/1	1/1	4/5	3/4
Production Process	0/0	0/2	6/6	2/3
Competition in Advanced Development				
Performance	0/0	1/1	0/2	4/5
Materials	0/0	1/1	2/4	2/3
Production Process	0/0	0/0	3/6	2/2
With Prototypes in Advanced Development				
Performance	0/0	1/1	1/2	4/4
Materials	0/0	1/1	2/3	3/3
Production Process	0/0	0/0	4/5	2/2
FSD Subsystem Competition				
Performance	0/0	1/1	1/4	0/6
Materials	0/1	1/1	0/5	1/4
Production Process	0/0	0/2	2/6	0/3
Independent Testing				
Performance	0/0	0/1	1/4	2/4
Materials	0/1	0/1	1/4	2/3
Production Process	0/0	0/2	2/5	1/2
Independent Cost Estimates				
Performance	0/0	1/1	2/4	3/3
Materials	0/1	1/1	2/3	3/3
Production Process	0/0	0/2	4/4	2/2
Low-Rate Initial Production Phase				
Performance	0/0	1/1	2/3	4/6
Materials	1/1	1/1	2/4	3/4
Production Process	0/0	1/2	4/5	2/3
System Production Competition				
Performance	0/0	1/1	1/3	2/6
Materials	0/1	1/1	1/4	2/4
Production Process	0/0	0/2	3/5	1/3
Subsystem Production Competition				
Performance	0/0	1/1	3/3	2/6
Materials	1/1	1/1	1/4	3/4
Production Process	0/0	2/2	2/5	2/3
System Warranty				
Performance	0/0	0/0	2/3	2/6
Materials	1/1	0/0	0/4	3/4
Production Process	0/0	1/2	1/4	2/3
Subsystem Warranties				
Performance	0/0	0/0	0/3	2/5
Materials	0/1	0/0	0/3	2/4
Production Process	0/0	0/2	0/3	2/3

Competition at the system level during the production phase was not likely to be used as a means of providing an alternative solution to requirements for advances in production process technologies. Nor were warranties consistently used to ensure that contractors would deliver on their performance and cost objectives as affected by their requirements for advances in technology. However, the only warranties used at the subsystem level were for munitions with extensive requirements for advances in performance, materials, and production technologies.

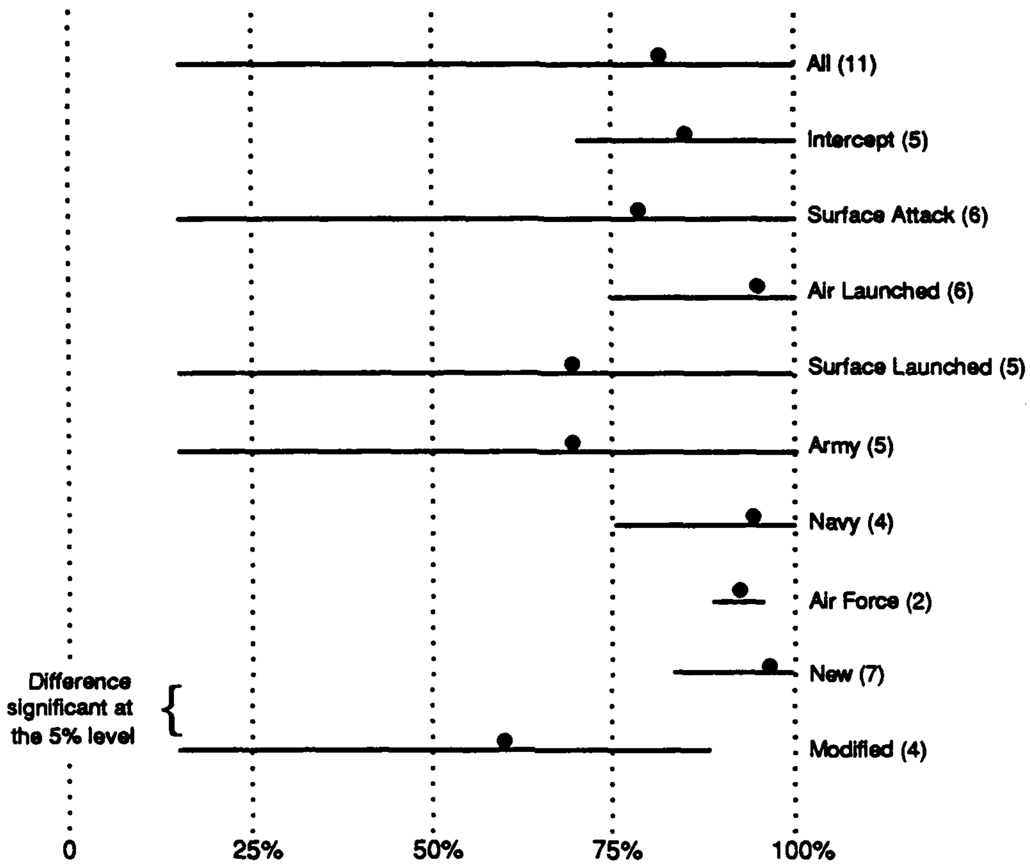
The data from the questionnaire provided conflicting evidence of the extent to which anticipated levels of technology advance differed from actual levels of technology advance, in terms of performance, materials, and production processes.[7] However, several of the contractors indicated that the requirements for advances in technology had been underestimated. A further possibility is that difficulties in technology advance had been anticipated, but were deliberately understated in efforts to sell the program. A more detailed analysis of technology time-of-arrival is required in order to estimate the differences between anticipated and actual levels of required technology advance and to evaluate the risks associated with high levels of technology advance.

C. REQUIREMENTS FOR INCREASES IN RESOURCES

Data were also obtained from the questionnaires on the increases in three categories of resources required during the acquisition program. The three categories of resources are: the test equipment used during development and production; production facilities; and production tooling. Increase in production facilities was measured in terms of percentage of square feet of new floor area. Increases in production tooling and test equipment were measured in terms of percentage of dollar values of augmentation of existing tooling or test equipment, respectively. That there are many problems in using dollar values for equipment purchased at different periods in time is well recognized. Because of usage of old equipment, and quality improvements embodied in new equipment, calculations using dollar values are not completely accurate. However, such calculations do give indications of relative magnitudes. Data on the increases in these three resources were again limited to the guidance subsystem.

The contractors submitted data showing both the percentage increases in resources anticipated to be required at the time the development program was initiated, and the percentage increases in resources actually required during the acquisition program. The data are summarized in terms of the low, high, and mean percentage increases in resources

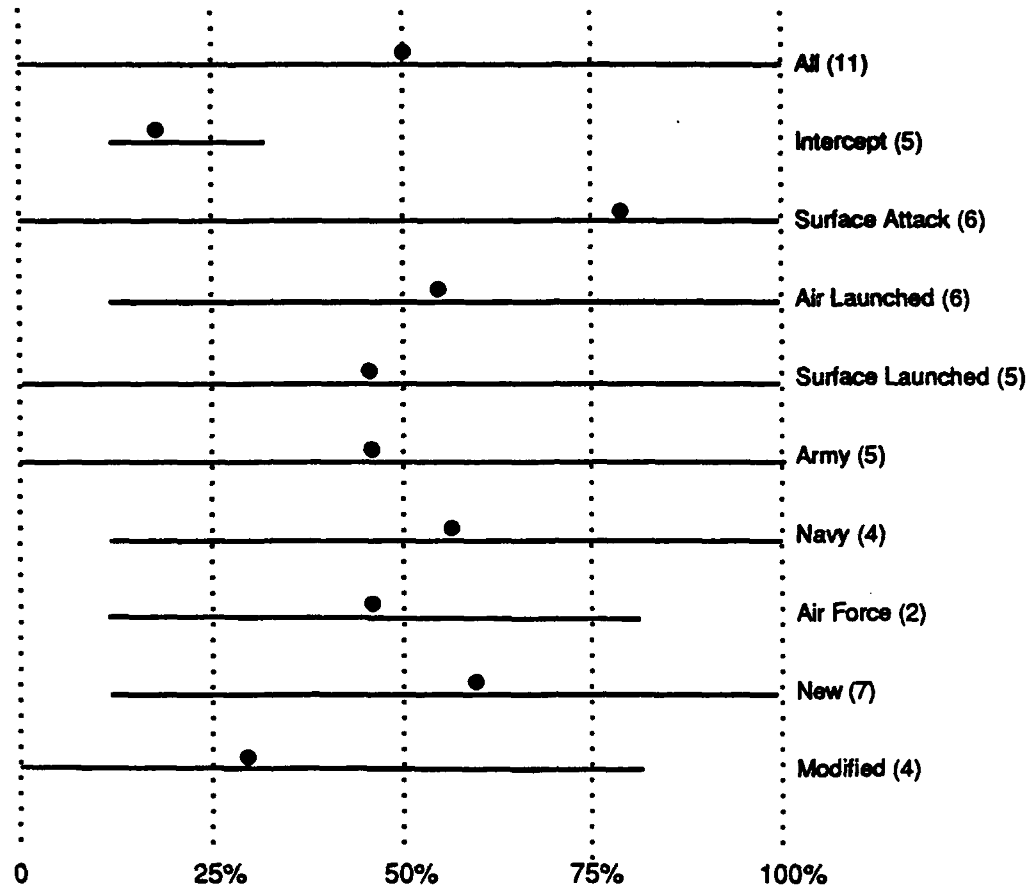
for the munitions in the sample, so as to be unidentifiable as to contractor or munition. These data are shown in Figures III-2, III-3, and III-4, for the percentage requirements for new test equipment, production facilities, and production tooling, respectively.[8]



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure III-2. Range of New Test Equipment Requirements for Each Category of Munition

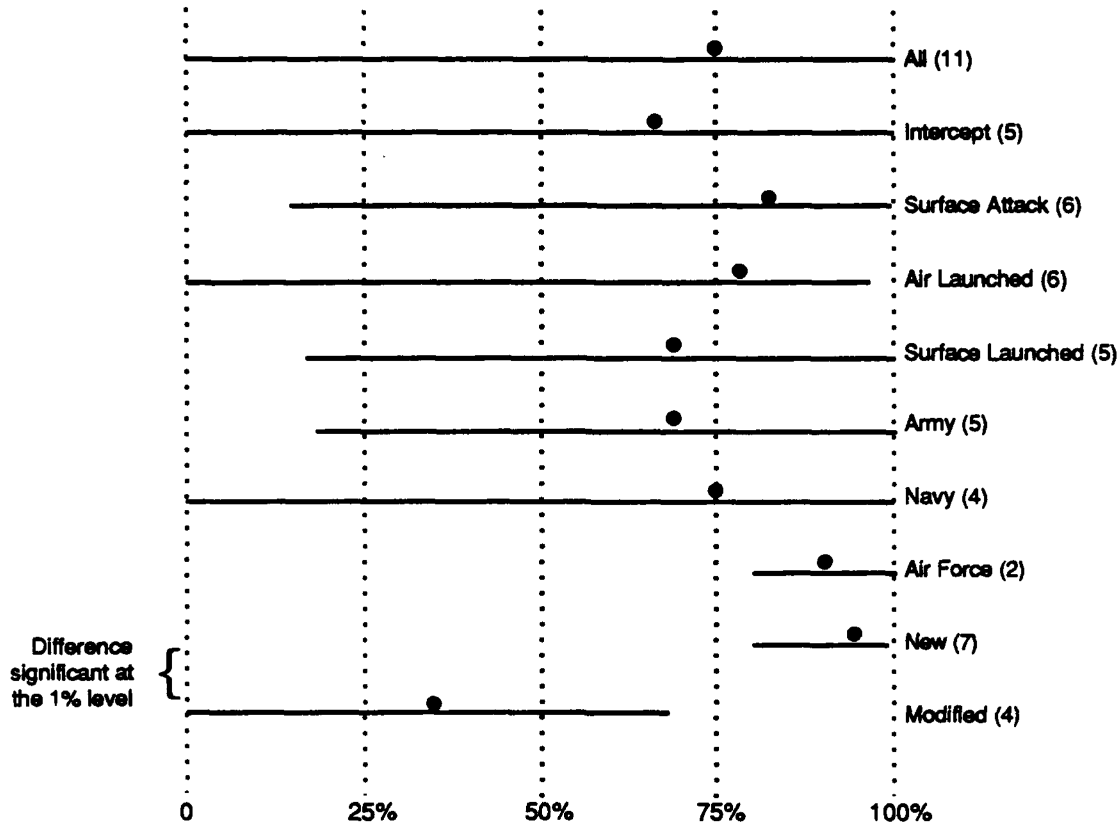
While there appear to be differences in the percentage requirements for new resources based on the categories of the munitions, only the differences between new and modified munitions are statistically significant. The percentage requirements for new test equipment and tooling were significantly higher for new munitions than for modified munitions. Percentage requirements for new resources were not significantly affected by when the munitions started development.[9]



Notes: *Numbers in parentheses are sample sizes. Bullets (●) indicate the means.*

Figure III-3. Range of New Facilities Requirements for Each Category of Munition

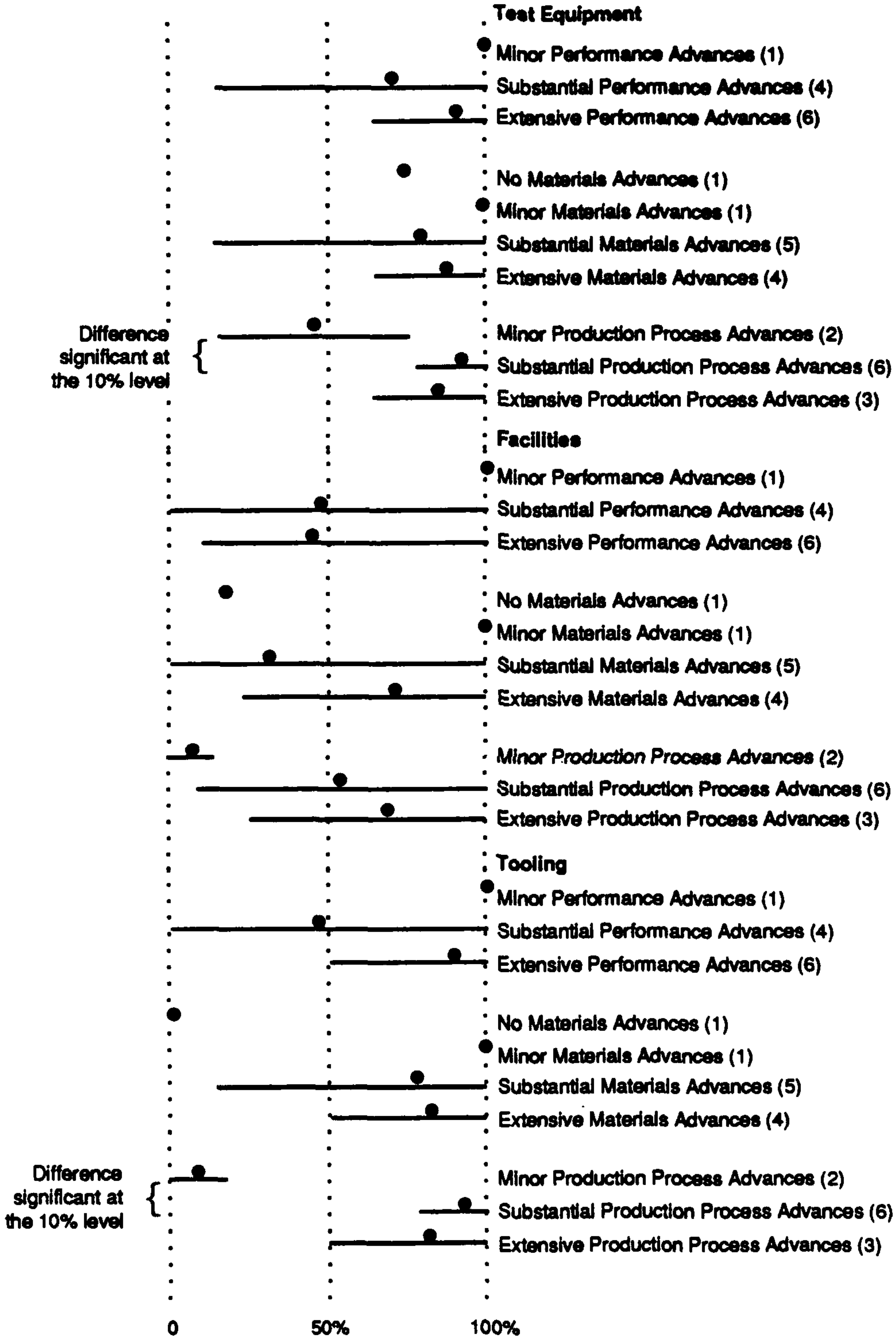
Percentage requirements for new facilities and new tooling were directly related to the percentage requirements for new test equipment, but not to each other.[10] Besides being highly related to each other, the percentage requirements for new test equipment and new tooling were both related to the level of technological advance required for the production processes. Munitions that required substantial or extensive advances in production process technology also required higher percentages of new test equipment and tooling than did munitions that required only minor advances in production process technology, as shown in Figure III-5.[11] The percentage requirements for new test equipment and tooling were not significantly related to the required levels of advance in performance or materials technology. Nor were the percentage requirements for new facilities significantly related to the required levels of advance in performance, materials, or production technology.



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

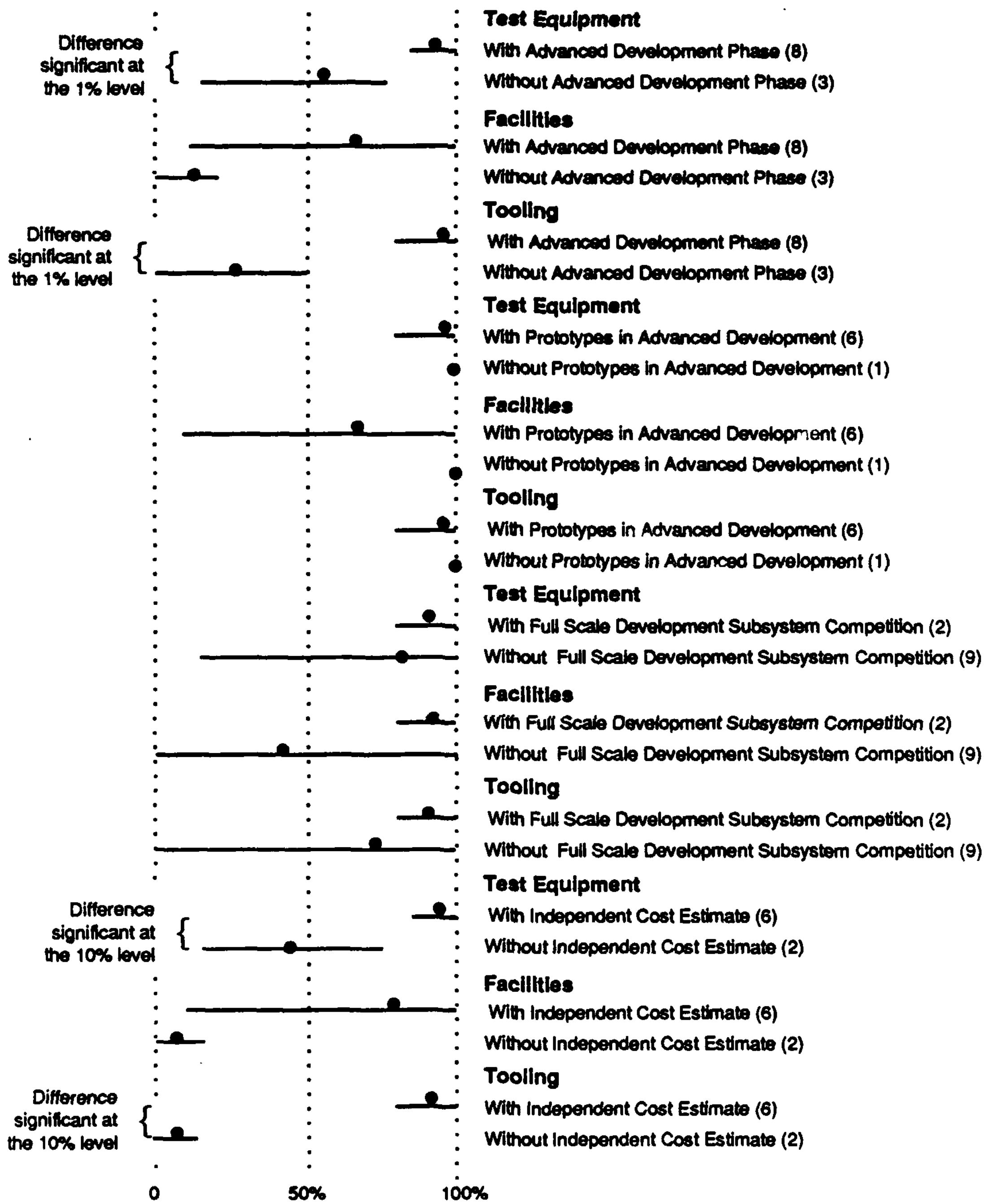
Figure III-4. Range of New Tooling Requirements for Each Category of Munition

Munitions with higher percentage requirements for new test equipment and new tooling were more likely to have been subjected to advanced development phases, independent cost estimates, and low-rate initial production phases than were munitions with lower percentage requirements for new test equipment and tooling, as shown in Figure III-6.[12] These results, and the strong statistically significant relationships between the percentage requirements for new test equipment and tooling and the required levels of advance in production technology (referred to earlier) support the findings in the previous section that advanced development and independent cost estimates were more likely to be applied to munitions with requirements for substantial or extensive advances in production technology. The percentage requirements for new resources did not vary significantly with the applicability of other acquisition policies, as shown in Figure III-6.



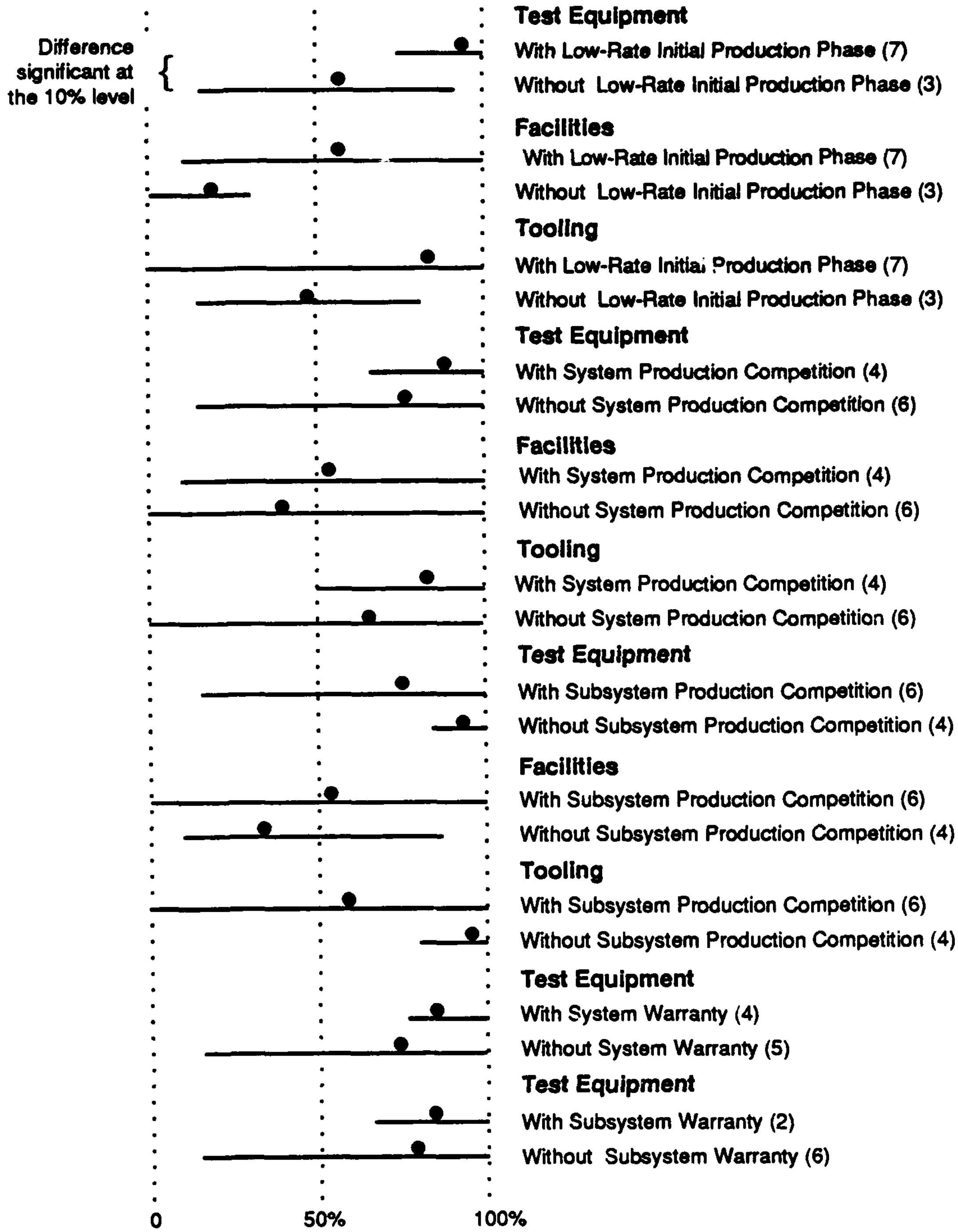
Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure III-5. Range of New Resource Requirements for Each Required Level of Technological Advance



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure III-6. Range of New Resource Requirements for Applications of Each Acquisition Policy



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure III-6. Range of New Resource Requirements for Applications of Each Acquisition Policy (Continued)

The quantitative data provided by the contractors show six differences for four separate munitions, between the anticipated and actual requirements for the three types of resources.[13] Three of the differences were small, for three different munitions. The other three differences were for large underestimates for each of the three resources for one munition; that munition had a much higher than average development schedule growth factor and production cost growth factor, but surprisingly, it had little development cost growth. There were no significant relationships between errors in the anticipated percentage requirements for new test equipment, new facilities, and new production tooling.[14]

D. STABILITY OF FUNDING

A frequently heard complaint is that one of the major problems in acquisition of munitions (and other defense systems) is that funding levels are not stable. Exactly what "stability" means in this context is not clear. Year-to-year variability in actual funding can be expected for a number of reasons. Development funding could rationally be expected to be lower in the early phases of development when concepts are being developed and evaluated and the overall design is being formulated. As more detailed design work proceeds, the rate of development spending could be expected to increase, and later to taper off as the project nears production. Likewise, production spending rates could be expected to be lower initially for long lead-time items and low-rate production. For these reasons, some variation in spending and funding rates should be expected.

What is more likely meant by the complaint of instability of funding is that the contractor cannot reliably estimate what the funding will be for future years. The issue is predictability. At a macro level, whether the overall defense appropriation levels are expected to increase or decrease will likely affect the contractor's estimate of future funding for specific programs. At a more micro level, the difference between the amount appropriated by Congress for a specific munition in a given year and the corresponding amount submitted in the President's budget is important.

Based on these two concepts of funding stability, two quantitative measures were calculated. The first measure, procurement macro-stability, consists of compound annual growth rates in defense total obligational authority (TOA) in constant FY 1989 dollars.[15] The measure of procurement macro-stability for each munition in the sample was calculated from the start of production to either the completion of production or the end of FY 1989 (whichever is earlier).

The second measure, procurement micro-stability, is based on annual procurement budget and appropriation amounts shown in the SARs for the munitions in the sample. Because of differences in the extent to which appropriation and budget data are contained in the SARs, procurement micro-measures could not be calculated over all appropriate years for all munitions in the sample, and development micro-measures could not be calculated for any of them. The procurement micro-measure was calculated as the root mean squared annual percentage error, where the annual error was defined as[16]:

$$\frac{\text{(the appropriated amount for the munition)} - \text{(the budgeted amount for the munition)}}{\text{(the budgeted amount for the munition)}}$$

The two funding stability measures are shown in Table III-4 for each munition for which they could be calculated. The range of macro-measures is shown in Figure III-7 and the range of micro-measures is shown in Figure III-8, for each category of munition.[17,18] The only statistically significant difference in procurement TOA annual growth rates is between Army and Air Force munitions; the two Air Force munitions entered procurement at a time when the procurement TOA was decreasing at a rate greater than experienced for any of the Army munitions. The decreasing procurement TOA for the Air Force munitions was reflected in a lower mean procurement macro-stability measure for the Air Force munition than for the Army or Navy munitions. The only statistically significant difference in procurement micro-stability measures was between the Navy and Air Force munitions. There were no statistically significant differences between Army and Navy munitions, in either the procurement TOA annual growth rates or the procurement micro stability measure.

The procurement TOA annual growth rates showed a statistically significant trend over time.[19] They tended to be lower for those munitions that entered production later. This simply reflects the large TOA growth rates in the early 1980s, and accounts for the differences between Air Force and Army munitions alluded to above.

The root mean squared percentage difference between program procurement requests and appropriations (the procurement micro-stability measure) did not show any trend over time. Nor were there any statistically significant relationships between either of the two stability measures or with any of the three resource requirement categories discussed in the preceding section.[20] There are no reasons to believe that there should be any relationships between the procurement TOA growth rates and either the required levels

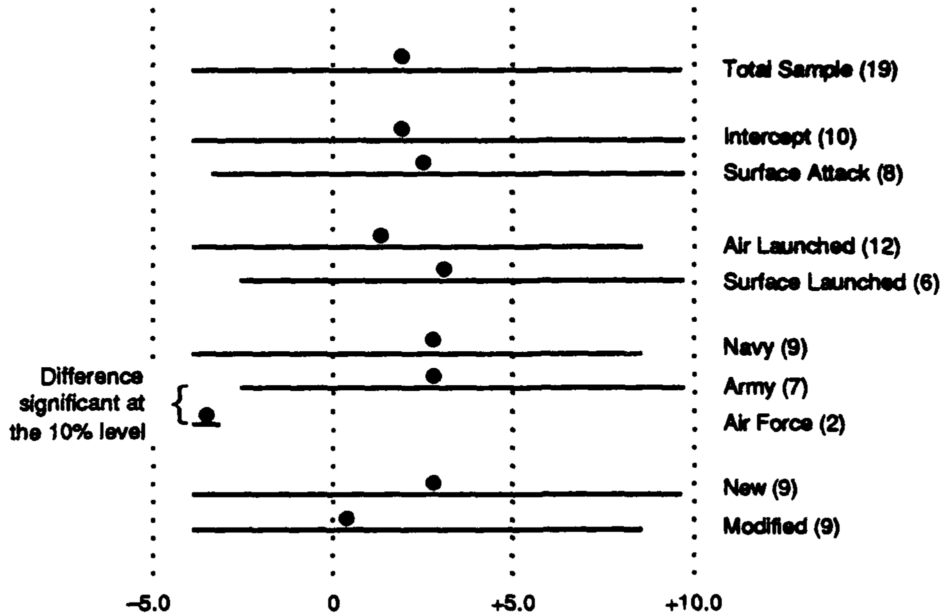
of technical advance discussed previously or any of the acquisition policies discussed in Chapter II.

Table III-4. Funding Stability Measures

Designator	Title	Procurement TOA Compound Annual Growth Rate	Root Mean Squared Annual Percentage Difference Between Program Procurement Requests and Appropriations
A/RIM-7E	Sparrow III B CW	-3.98	-
AIM-7F	Sparrow III Pulse Doppler	6.61	-
A/RIM-7M	Sparrow III Monopulse	-2.34	.073
AIM-9L	Sidewinder	8.49	-
AIM-9M	Sidewinder	2.50	.247
AIM-54A	Phoenix	-0.84	-
AIM-54C	Phoenix	4.45	.122
AIM-120A	AMRAAM	-3.99	.479
FIM-92A	Stinger-Basic	9.79	.119
FIM-92A	Stinger-POST/RMP	-2.34	-
AGM-65D/F/G	IIR Maverick	-3.37	.508
A/R/UGM-84A/C/D	Harpoon	4.57	.119
AGM-88A	HARM	2.50	.276
AGM-114A/B	Hellfire	-0.15	.092
BGM-71A	TOW I	0.38	-
BGM-71D	TOW II	-0.15	.236
-	MLRS	4.45	-
M-712	Copperhead CLGP	5.91	.608
-	5" Deadeye SALGP	-	-
Number of Observations		18	11

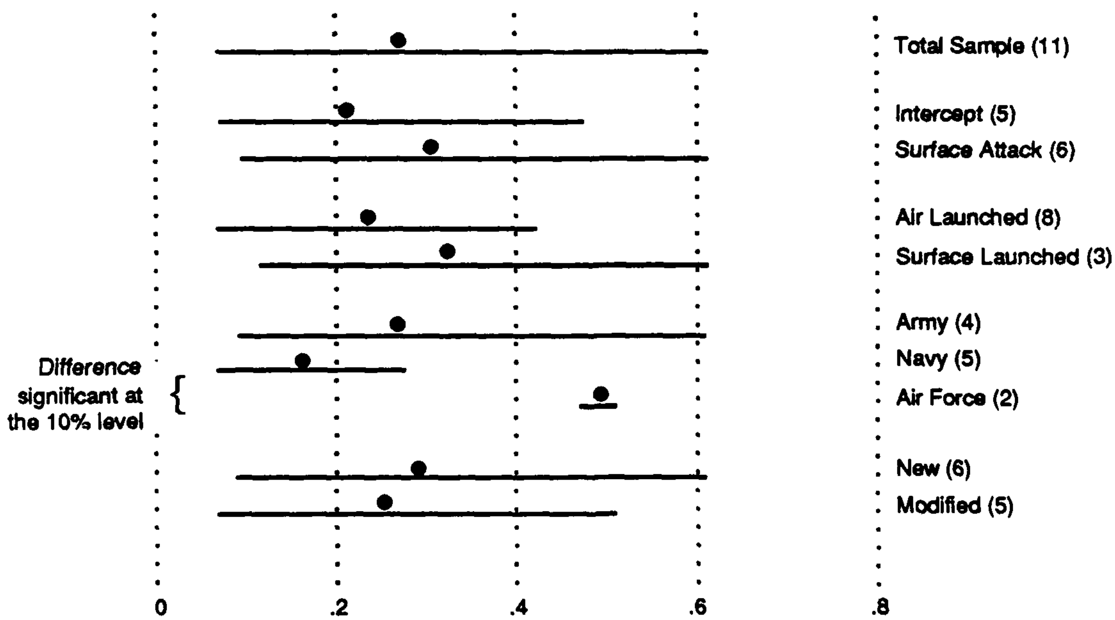
Average micro-stability measures were higher, as shown in Figure III-9, with but one exception (no materials technology advance versus minor materials technology advance) for higher levels of required technological advance.[21] This would imply that munitions with higher requirements for advances in technology were more likely to encounter instability of funding. However, none of these differences in procurement micro-stability between the required levels of technological advance are statistically significant.

Whether or not certain of the acquisition policies were applied during the production phase did not have any statistically significant effects on procurement micro-stability, as shown in Figure III-10.[22]



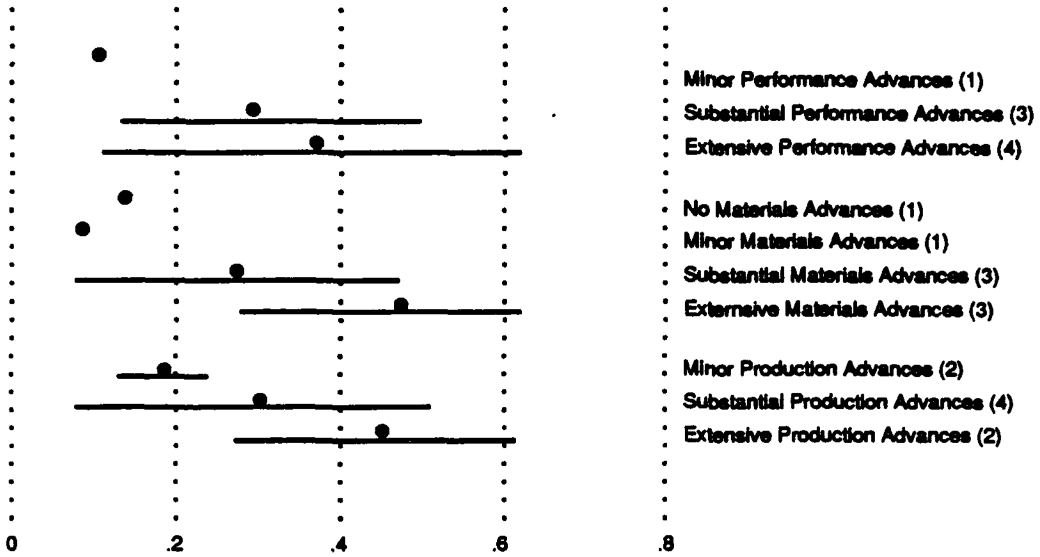
Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure III-7. Range of Procurement TOA Annual Growth Rates for Each Category of Munition



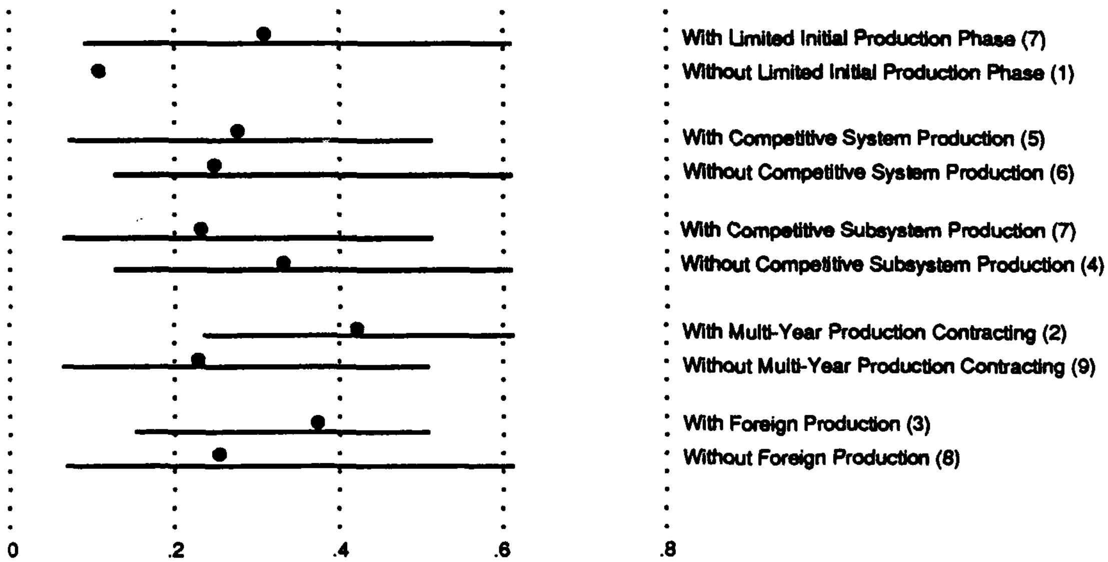
Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure III-8. Range of Root Mean Squared Annual Percentage Differences Between Program Procurement Requests and Appropriations for Each Category of Munition



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure III-9. Range of Root Mean Squared Annual Percentage Differences Between Program Procurement Requests and Appropriations, for Each Required Level of Technological Advance



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure III-10. Range of Root Mean Squared Annual Percentage Differences Between Program Procurement Requests and Appropriations, for Applications of Each Acquisition Policy

E. OVERLAP BETWEEN DEVELOPMENT AND PRODUCTION

The overlap between development and production is defined as the interval (in months) between the startup of production and the initial operation capability (IOC) date. The end of the development phase is commonly defined as the end of development testing and evaluation, but because of limitations in the test data in the SARs, it was not possible to use this definition for the case studies in Volume II. Instead, development is here defined as ending upon the IOC date. Production is generally defined throughout this report as starting with Milestone III or IIIA (MS III), as appropriate. Using these definitions and data from the case studies in Volume II, development/production overlap ratios were calculated for twelve of the munitions in the sample as:

$$\frac{\text{IOC} - \text{MS III}}{\text{IOC} - \text{MS II}}$$

These ratios are shown in Table III-5.[23] Development/production overlap ratios were not calculated for the MLRS, which went directly from advanced development to the production phase, or for the 5" Deadeye SALGP, which never entered production. Development/production overlap ratios could not be calculated for the AIM-7E and F Sparrow, AIM-54A Phoenix, Stinger-Basic, and TOW I, because of insufficient information on MS II, MS III, and IOC dates in the SARs.

Two caveats should be kept in mind about the use of these ratios. The first is that a value greater than zero is entirely reasonable and is to be expected, because some production must take place to provide the munitions for the IOC. Without some overlap between development (as here defined) and production, there can be no IOC. Because of this, it may not be possible to say whether or not the development/production overlap ratio for a particular munition is excessive. What can be said when development/production overlap ratios for different munitions are compared, is that a higher ratio is worse than a lower ratio.

The second caveat is that the length of the interval between the start of the production phase and IOC will be the greater of: (1) any overlap or concurrency between the start of the production phase and completion of testing and evaluation; (2) the lead-times for startup of production; and (3) any delays caused by the availability of complementary platforms or sensors. For example, AIM-9L Sidewinder experienced concurrency between the start of the production phase (April 1976) and the completion of testing (January 1978,

just four months prior to the IOC in May 1978). Copperhead experienced great difficulties in the startup of production, as reflected in a 37 month interval between production startup and IOC. The Hellfire's IOC was delayed significantly beyond the completion of development testing due to unavailability of the AH-64 Apache. Because of these two caveats, care must be taken in interpreting differences in the development/production overlap ratios between the munitions in the sample.

Table III-5. Development/Production Overlap Ratios

Designator	Title	Development/ Production Overlap Ratio
A/RIM-7E	Sparrow III-B CW	I.U.
AIM-7F	Sparrow III Pulse Doppler	I.U.
A/RIM-7M	Sparrow III Monopulse	.037
AIM-9L	Sidewinder	.346
AIM-9M	Sidewinder	.241
AIM-54A	Phoenix	I.U.
AIM-54C	Phoenix	.689
AIM-120A	AMRAAM	.072
FIM-92A	Stinger-Basic	.371
FIM-92A	Stinger-POST/RMP	.I.U.
AGM-65D/F/G	IIR Maverick	.342
A/R/UGM-84A/C/D	Harpoon	.625
AGM-88A	HARM	.116
AGM-114A/B	Hellfire	.416
BGM-71A	TOW I	I.U.
BGM-71D	TOW II	.410
–	MLRS	N.A.
M-712	Copperhead CLGP	.529
–	5" Deadeye SALGP	N.A.

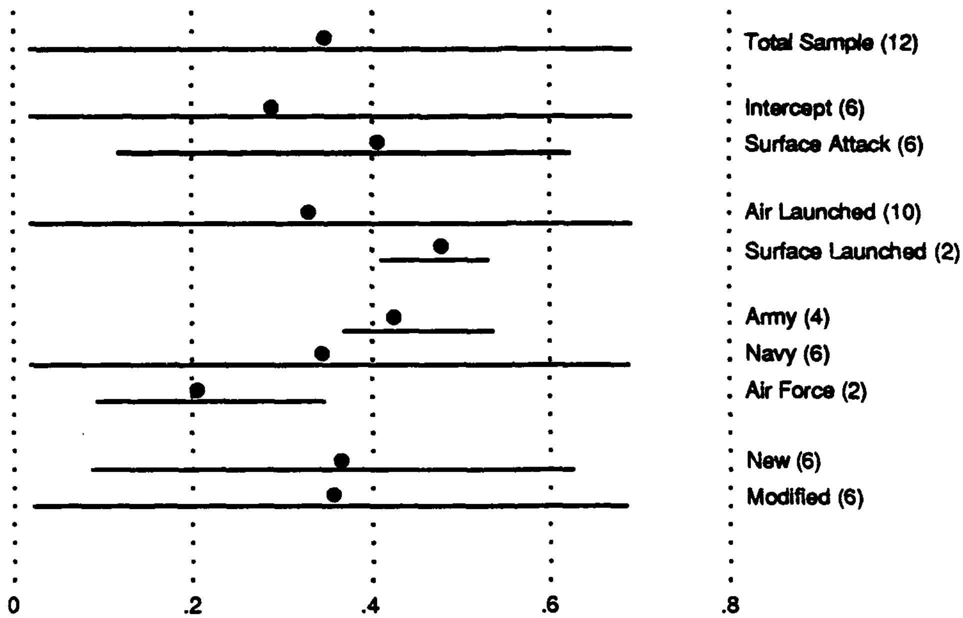
N.A. = Not applicable.

I.U. = Information unavailable.

There were no statistically significant differences between development/production overlap ratios based on categories of munitions, as shown in Figure III-11.[24] Overlaps between development and production did tend to decrease over time, with lower ratios for the munitions that entered production later.[25] Development/production overlap ratios were also directly related to the procurement TOA annual growth rates, which should be expected because of the strong inverse relationship between production start dates and procurement TOA annual growth rates discussed in the preceding section. However, there

was no statistically significant relationship between the development/production overlap ratios and the procurement micro-stability measures.

The development/production overlap ratios did not vary significantly with either the percentage requirements for new resources, or with the requirements for advances in technology (as shown in Figure III-12).[26, 27] However, munitions with system production competition did tend to have lower development/production overlap ratios than did munitions without, and those differences were statistically significant, as shown in Figure III-13.[28]



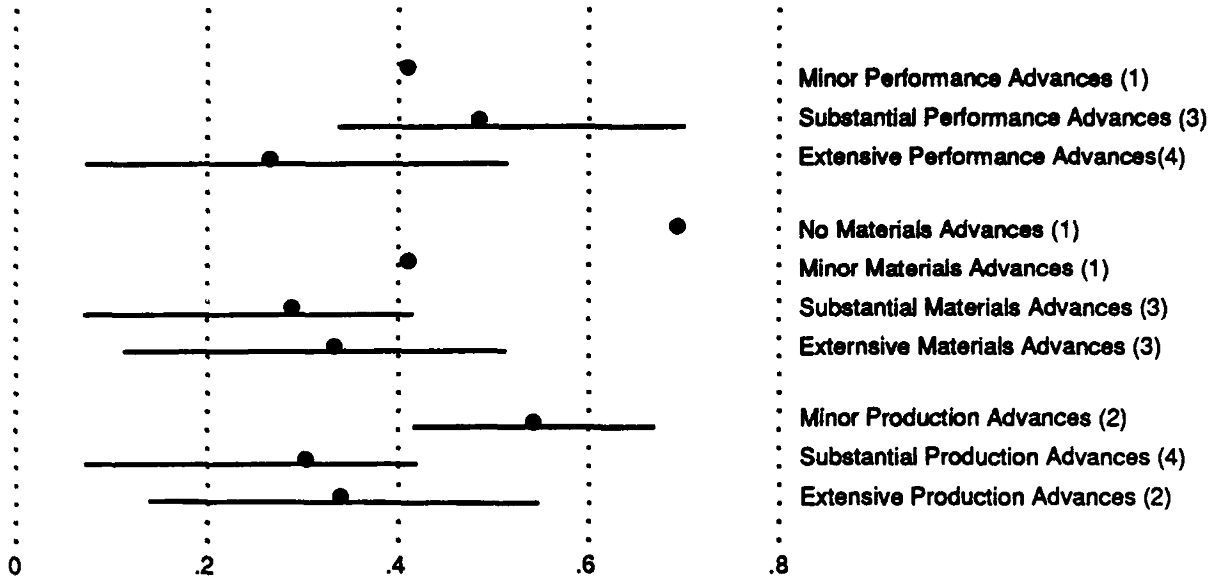
Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure III-11. Range of Development/Production Overlap Ratios for Each Category of Munition

F. AVAILABILITY OF REQUIRED COMPLEMENTARY SYSTEMS

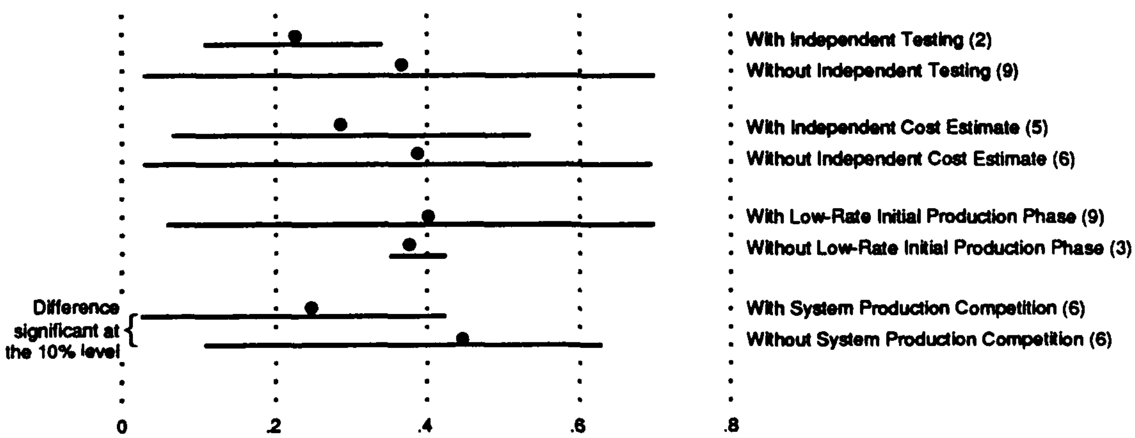
The development schedules for two of the nineteen munitions in the sample were significantly affected by the availability of required complementary systems. The AMRAAM planned development schedule was compressed in order to provide missiles for use by F-16 aircraft in the NATO theater. The IOC of the Hellfire was delayed from FY 1985 until July 1986 because of delays in development and operational schedule for the AH-64 helicopter. In both cases, the complementary system was the platform. For several of the other munitions in the sample, the use of special target designators was required, but

the development schedules for those munitions were not adversely affected by the availability of the designators.



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure III-12. Range of Development/Production Overlap Ratios for Each Required Level of Technological Advance



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure III-13. Range of Development/Production Overlap Ratios for Applications of Each Acquisition Policy

This may not always be the case in the future. The lesson is that the progress of a munition's acquisition program should not be managed in isolation; consideration should be given to the progress of the acquisition programs for complementary systems such as platform and target designators. In the Hellfire example, the actual engineering development program could have been increased by at least 9 months without adversely affecting the July 1986 IOC of the AH-64 armed with that missile. It would have been a waste to expend funds for overtime during the development of the Hellfire.

IV. COMPARISONS OF PROGRAM OUTCOMES

In this chapter, the nineteen munitions are compared in terms of several measures of program success, and are evaluated in terms of how those measures were related to the munition characteristics, the acquisition policies that were applied, and the risks that were encountered. The measures of program success used are:

- Satisfaction of operational and technical requirements;
- Development schedule growth;
- Development quantity growth;
- Development cost growth;
- Production cost growth;
- Production quantity growth;
- Production stretchout
- Total program cost growth.

These measures were selected because data for each could be obtained from the Selected Acquisition Reports (SARs). For other measures of program success that could also be defined, the data were not readily available.

A. SATISFACTION OF OPERATIONAL AND TECHNICAL REQUIREMENTS

Satisfaction of operational and technical requirements is defined in the same terms as used in the SARs. Operational requirements include measures of reliability and maintainability. Technical requirements include measures of size and weight, although weight is included under operational requirements in at least one of the SARs (AIM-7F Sparrow). Performance requirements such as range, velocity, and accuracy are included under either operational requirements or technical requirements in the SARs, depending upon the particular munition. Because of the somewhat arbitrary assignment of these requirements in the SARs, the two types of requirements have been combined in the following paragraphs.

The data showing whether or not the operational and technical requirements listed in the SARs were totally satisfied are shown in Table IV-1. Two of the munitions in the

sample have not completed development testing: the AMRAAM and the Stinger-POST/RMP. Although development testing has not been completed for the Stinger-POST/RMP, testing to date has shown deficient reliability.

Table IV-1. Satisfaction of Operational and Technical Requirements

Designator	Title	New/ Mod	Requirements Satisfied
A/RIM-7E	Sparrow III-B CW	Mod	Yes
AIM-7F	Sparrow III Pulse Doppler	Mod	Overweight, deficient speed, range and altitude
A/RIM-7M	Sparrow III Monopulse	Mod	Deficient reliability and guidance probability
AIM-9L	Sidewinder	Mod	Deficient head-on range
AIM-9M	Sidewinder	Mod	Deficient head-on range and flare discrimination
AIM-54A	Phoenix	New	Launch weight 5 percent over
AIM-54C	Phoenix	Mod	Yes
AIM-120A	AMRAAM	New	Unknown-development testing not yet completed
FIM-92A	Stinger-Basic	New	Yes
FIM-92A	Stinger-POST/RMP	Mod	Unknown-development testing not yet completed
AGM-65D/F/G	IIR Maverick	Mod	Yes
A/R/UGM-84A/C/D	Harpoon	New	Launch weight 5 percent over
AGM-88A	HARM	New	Deficient classified requirement
AGM-114A/B	Hellfire	New	5 percent overweight
BGM-71A	TOW I	New	Slightly overweight
BGM-71D	TOW II	Mod	Yes
–	MLRS		
M-712	Copperhead CLGP	New	Yes
–	5" Deadeye SALGP	New	Yes

For ten of the seventeen munitions for which development testing had been completed, the requirements listed in the SARs were not totally satisfied. Head-on-range and flare discrimination requirements were not completely satisfied for the AIM-9L and AIM-9M Sidewinder missiles, but the attained performance of these missiles is militarily useful. The Harpoon, the Hellfire, and the TOW I are all slightly overweight, but not enough to require additional development effort to reduce the weight. The accuracy of the MLRS is below specifications, but again, the demonstrated accuracy is militarily useful, and the additional cost that would be required to achieve the specified accuracy was judged to be excessive. For the one munition in the sample that was cancelled prior to production (5" Deadeye SALGP), both the operational and technical requirements listed in the SAR were satisfied.

Satisfaction of the operational and technical requirements listed in the SARs for each category of munition is shown in Table IV-2. Satisfaction of operational and technical requirements did not differ significantly between the various categories of munitions.[1]

Table IV-2. Differences Between Munition Categories and Satisfaction of Operational and Technical Requirements

	Requirements Satisfied	Requirements Not Satisfied	Total
Total Sample	7	10	17
Intercept	3	5	8
Surface Attack	4	5	9
Air Launch	3	8	11
Ground Launch	4	2	6
Army	3	3	6
Navy	3	7	10
Air Force	1	0	1
New	3	6	9
Modification	4	4	8

Of the seven munitions whose requirements were completely satisfied, 85.7 percent (=6/7) were deployed and 14.3 percent (=1/7) were never deployed. Of the sixteen munitions that have been deployed, 37.5 percent (= 6/16) completely satisfied the operational and technical requirements listed in the SARs, and 62.5 percent (= 10/16) did not fully satisfy those requirements. These results suggest that:

- A significant level of uncertainty exists about the relationship between deployment and satisfaction of the operational and technical requirements.
- There was some margin for design tradeoffs.
- Operational and technical requirements for a substantial share of these munitions may have been unrealistically stringent.

Whether or not the operational and technical requirements listed in the SARs were satisfied is not related to when the munition entered development.[2] Nor do any of the acquisition policies appear to have significantly increased the proportions of munitions satisfying those requirements, as shown in Table IV-3.[3]

Whether or not the requirements listed in the SARs were satisfied was not significantly related to the levels of technological advance that were required. As shown in Table IV-4, the proportion of munitions satisfying the operational and technical requirements was lower for munitions with extensive requirements for advances in

performance or production technology than for munitions with lesser requirements for technological advance, but the differences are not statistically significant.[4]

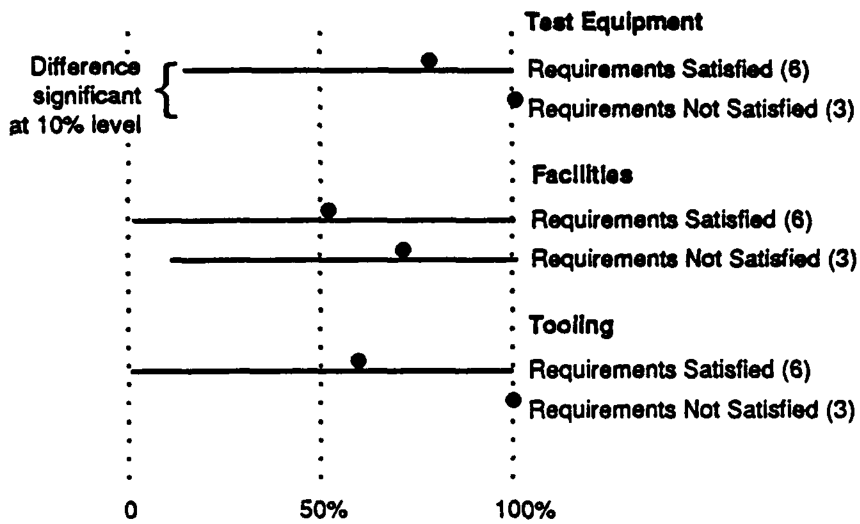
Table IV-3. Numbers of Munitions Satisfying Operational and Technical Requirements for Applications of Each Acquisition Policy

	Policy Applied	
	Yes	No
Advanced Development	4/11	3/6
Competitive Advanced Development	1/6	3/5
Advanced Development Prototype	2/9	4/7
Full Scale Development Subsystem Competition	1/4	6/12
Independent Testing	1/3	5/13
Independent Cost Estimate	3/5	3/10
Low-Rate Initial Production	3/8	3/6

Table IV-4. Numbers of Munitions Satisfying Operational and Technical Requirements for Required Levels of Technological Advance

	Requirements for Technology Advance				
	Off-the-Shelf	Minor	Substantial	Extensive	Total
Performance Advances					
Satisfied	0	0	4	2	6
Not Satisfied	0	1	0	2	3
Total	0	1	4	4	9
Materials Advances					
Satisfied	1	0	3	2	6
Not Satisfied	0	1	1	1	3
Total	1	1	4	3	9
Production Advances					
Satisfied	0	2	3	1	6
Not Satisfied	0	0	2	1	3
Total	0	2	5	2	9

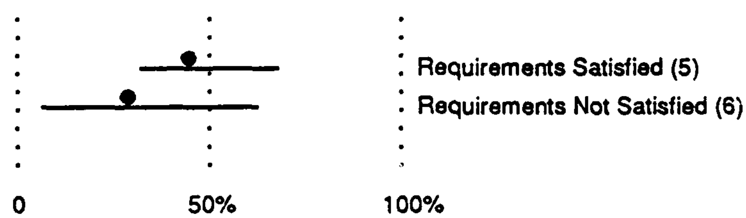
The ranges of percentage requirements for new resources were lower for the munitions satisfying the requirements than for the munitions that did not, as shown in Figure IV-1.[5] However, only the difference in test equipment requirements between the two groups of munitions was statistically significant. Each of the munitions that did not fully satisfy the requirements needed completely new test equipment.



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-1. Range of New Resource Requirements for Whether or Not Operational and Technical Requirements Were Satisfied

Differences in development/production overlap ratios, depending on whether or not the munitions satisfied the operational and technical requirements, as shown in Figure IV-2, were not statistically significant.[6]



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-2. Range of Development/Production Overlap Ratios for Whether or Not Operational and Technical Requirements Were Satisfied

Of the two munitions in the sample whose performance requirements were changed while the munitions were still in the development phase, one (IIR Maverick) satisfied its requirements, and the other (HARM) did not. The one munition in the sample whose IOC was delayed by the unavailability of its major platform (Hellfire, delayed by the development of the AH-64) did not fully satisfy its operational and technical requirements.

B. DEVELOPMENT SCHEDULE GROWTH

The durations of advanced development and full scale development, and the full scale development schedule growth factor, are shown in Table IV-5 for each of the munitions in the sample. Advanced development is defined as the number of months from Milestone I or the awarding of the advanced development contract (whichever is later), to Milestone II or the awarding of the full scale development (FSD) contract (whichever is earlier). FSD is defined as ending upon the IOC date. The development schedule growth factor is defined as the number of months from Milestone II to the actual IOC date, divided by the number of months from Milestone II to the IOC date planned at Milestone II. For those munitions for which there were no Milestone II dates in the SARs, the growth factor was based on the start of FSD.

As stated in Chapter II, only two of the modified munitions in the sample had advanced development (AIM-7M Sparrow and IIR Maverick), but all of the new munitions did. However, information as to when three of the munitions (Stinger-Basic, IIR Maverick, and 5" Deadeye SALGP) entered and completed advanced development could not be obtained.

The range of months in advanced development for the nine munitions for which dates are available, and the ranges of planned and actual months in FSD for each category of munition are shown in Figure IV-3.[7] Advanced development required over three years, on the average. FSD required over seven years, on the average. FSD for modified munitions actually took almost a year longer on the average than for new munitions.

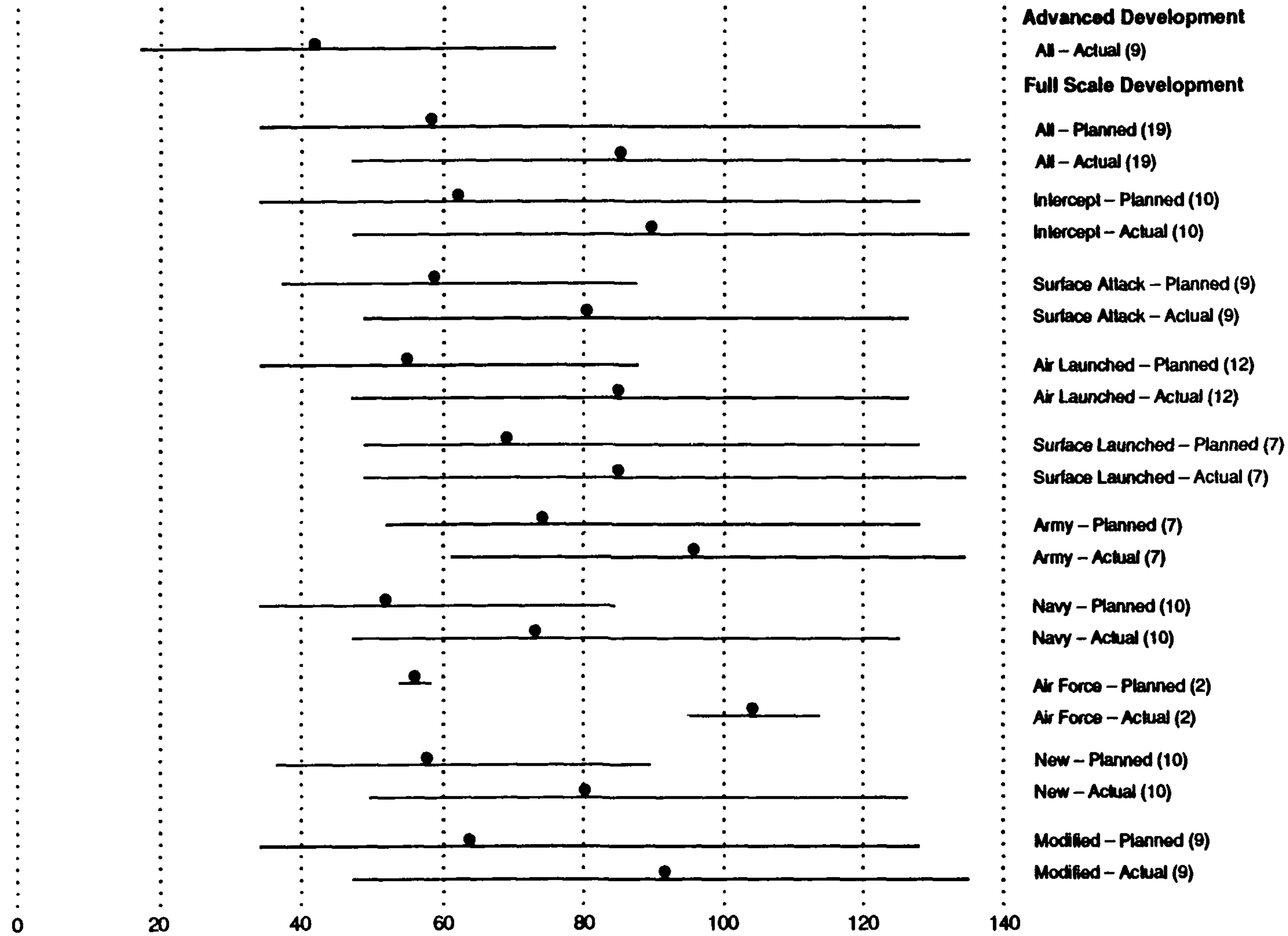
The actual months in FSD increased by almost half, on the average, over the planned duration. As shown in Figure IV-4, development schedule growth factors did not vary greatly between munition categories, except for the significantly higher development growth factors for the two Air Force munitions as compared to the seven Army munitions.[8] Development schedule growth was at least as bad for modified munitions as for new munitions; there was no statistically significant difference between these two groups.

There were no statistically significant differences in development schedule growth factors depending on whether or not the acquisition policies considered in this report were applied, as shown in Figure IV-5.[9] In particular, advanced development, prototyping, and competitive subsystem development did not result in significantly higher development

Table IV-5. Development Durations and Development Schedule Growth Factors

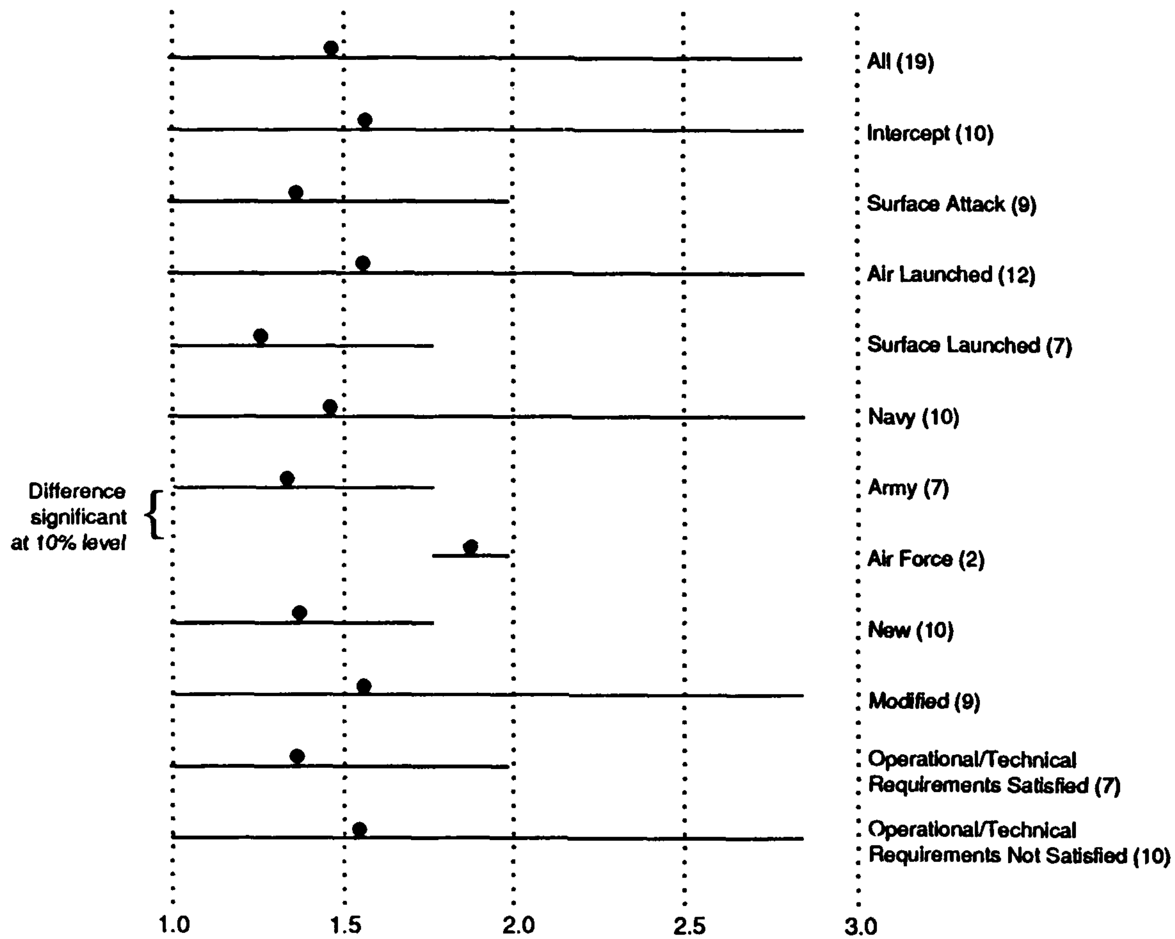
Designator	Title	New/ Mod	Advance Development Duration (Months)	Planned Full Scale Development Duration (Months)	Actual Full Scale Development Duration (Months)	Full Scale Development Schedule Growth Factor
A/RIM-7E	Sparrow III B CW	Mod		47	47	1.00
AIM-7F	Sparrow III Pulse Doppler	Mod		44	124	2.82
A/RIM-7M	Sparrow III Monopulse	Mod	38	39	57	1.46
AIM-9L	Sidewinder	Mod		33	81	2.45
AIM-9M	Sidewinder	Mod		78	79	1.01
AIM-54A	Phoenix	New	75	47	56	1.19
AIM-54C	Phoenix	Mod		84	122	1.45
AIM-120A	AMRAAM	New	46	54	94	1.74
FIM-92A	Stinger-Basic	New	I.U.	64	105	1.64
FIM-92A	Stinger-POST/RMP	Mod		127	134	1.06
AGM-65D/F/G	IIR Maverick	Mod	I.U.	57	113	1.98
A/R/UGM -84A/C/D	Harpoon	New	33	37	50	1.35
AGM-88A	HARM	New	45	57	69	1.21
AGM-114A/B	Hellfire	New	45	87	125	1.44
BGM-71A	TOW I	New	17	59	89	1.51
BGM-71D	TOW II	Mod		60	61	1.02
-	MLRS	New	32	70	70	1.00
M-712	Copperhead CLGP	New	40	52	90	1.73
-	5" Deadeye SALGP	New	I.U.	49	49	1.00
Low			17	33	47	1.00
High			75	127	134	2.82
Mean			42	57	85	1.48

I.U. - Information unavailable.



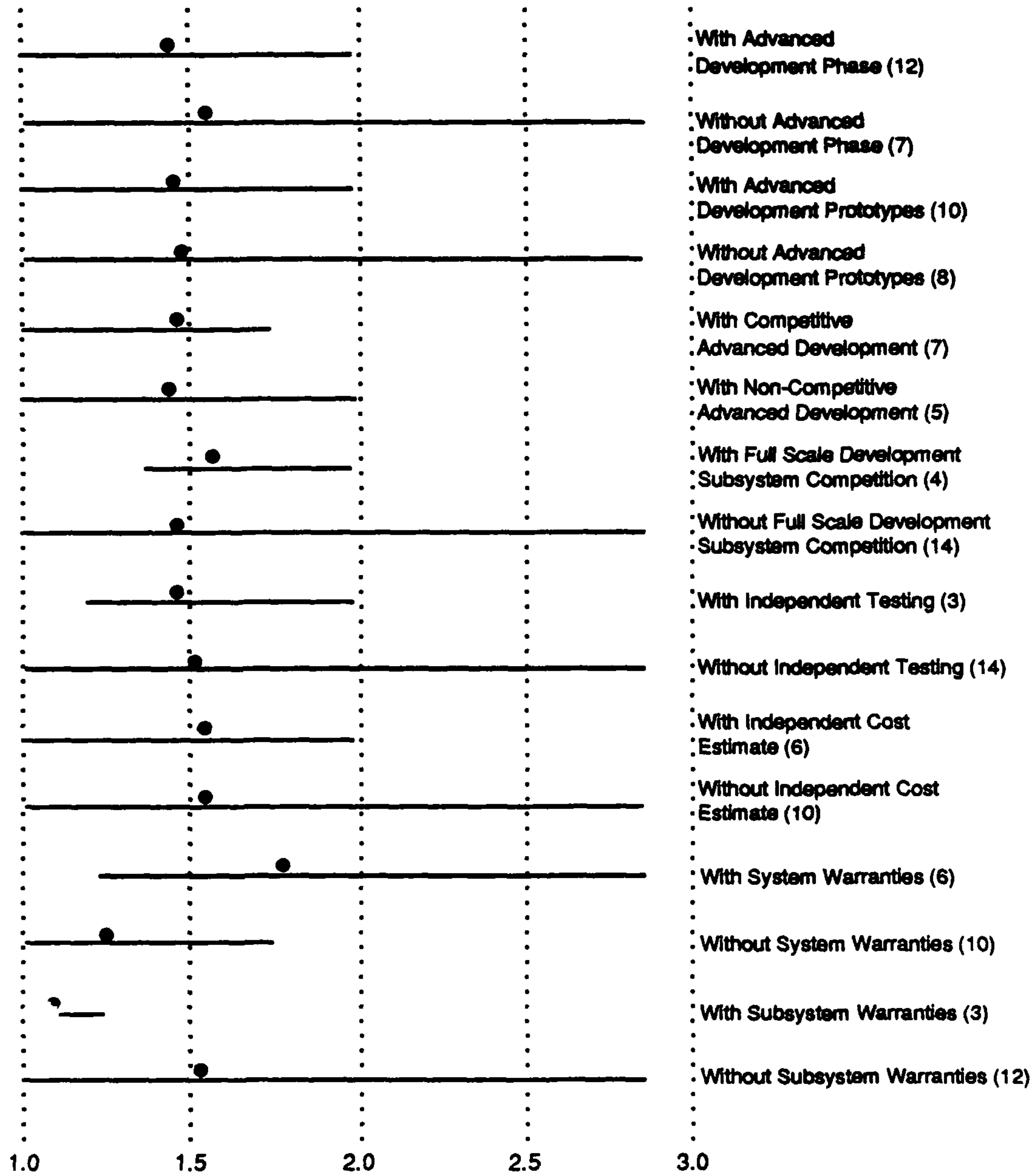
Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-3. Ranges of Advanced and Full Scale Development Months for Each Category of Munition



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

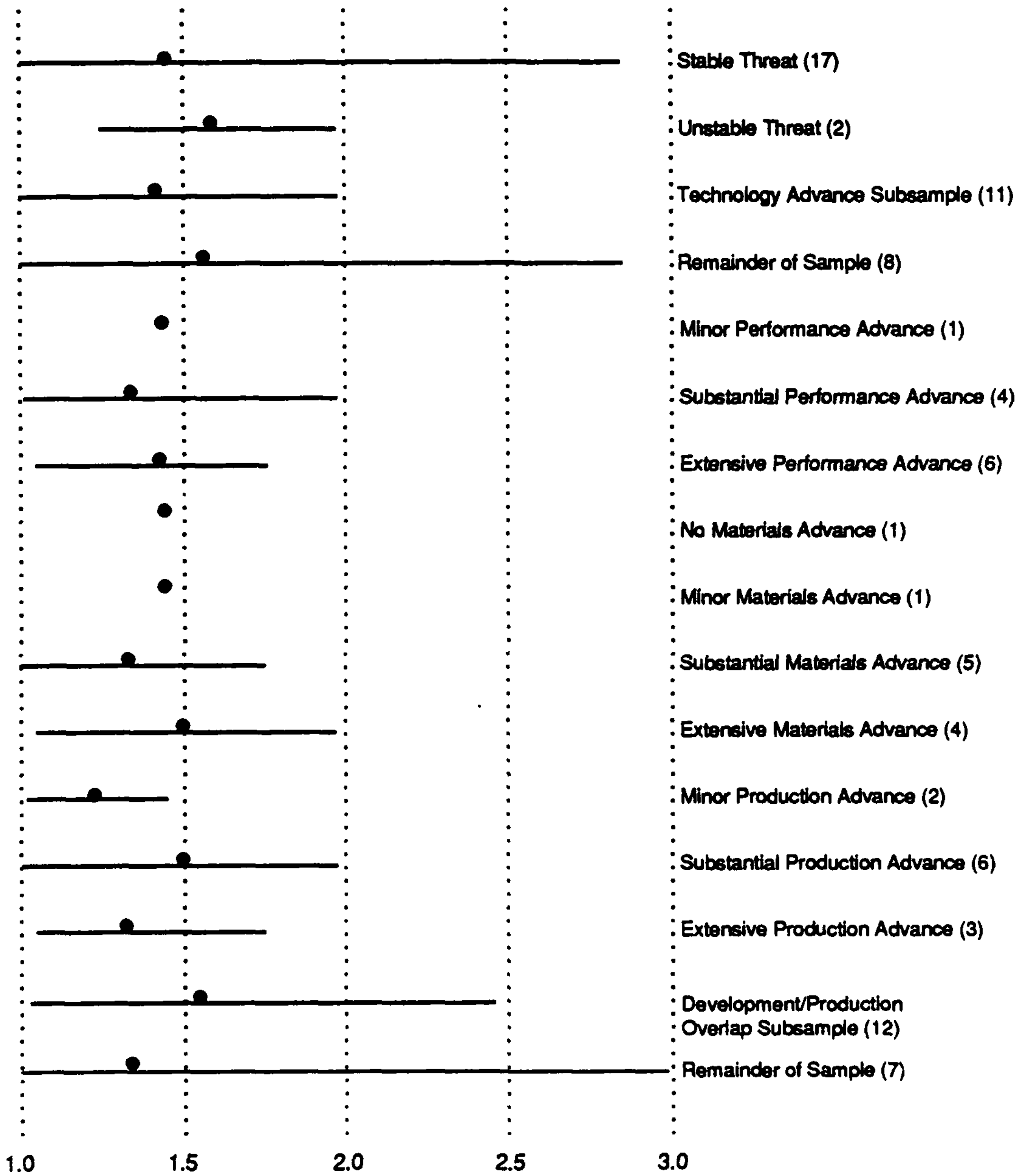
Figure IV-4. Range of Development Schedule Growth Factors for Each Category of Munition



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-5. Range of Development Schedule Growth Factors for Applications of Each Acquisition Policy

schedule growth. Furthermore, there were no statistically significant differences in development schedule growth factors related to the risks described in Chapter III, as shown in Figure IV-6.[10]



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-6. Range of Development Schedule Growth Factors for Each Category of Program Risk

Development schedule growth factors for the two munitions which had substantial threat changes did not differ from munitions for which the threats were stable. Munitions with extensive requirements for advances in technology did not suffer any significantly greater slippage in development schedules than did munitions with lesser requirements for advances in technology.

Requirements for new test equipment, facilities, or tooling did not affect the completion of the development schedule.[11] Munitions with low percentage requirements for new resources were no more likely to complete development on schedule than were munitions with high percentage requirements for new resources.

Development schedule growth factors did not show any significant changes over time. Nor were development schedule growth factors correlated with the development/production overlap ratios discussed in Chapter III.[12]

The numbers of months in advanced development had no statistically significant relationships with development schedule growth factors or the numbers of months in full scale development.[13] The absence of any correlation is in agreement with the absence of any statistically significant differences in development schedule growth factors between munitions with and munitions without advanced development phases, as shown in Figure IV-5.

C. DEVELOPMENT QUANTITY GROWTH

The numbers of test articles (both the development estimates and the current estimates) and the development quantity growth factors, are shown in Table IV-6. The development quantity growth factor is defined as the current estimate of the number of test articles shown in the latest SAR divided by the estimate shown in the SAR at the time of Milestone II approval. For those munitions for which Milestone II dates do not appear in the SAR, the growth factors were based on estimates as of the start of FSD from the earliest available SAR.

Two of the munitions in the sample have not completed development: the AMRAAM and the Stinger-POST/RMP. The first is a new munition and the second a modification. The current estimate of the number of test articles for the AMRAAM has been reduced below the development estimate by a third in order to limit the increased development costs experienced by that munition. The current estimate for the Stinger-

Table IV-6. Development Quantities and Development Quantity Growth Factors

Designator	Title	New/ Mod	Development Estimate Development Quantity	Current Estimate Development Quantity	Development Quantity Growth Factor
A/RIM-7E	Sparrow III B CW	Mod	44	44	1.00
AIM-7F	Sparrow III Pulse Doppler	Mod	34	134	3.94
A/RIM-7M	Sparrow III Monopulse	Mod	44	44	1.00
AIM-9L	Sidewinder	Mod	30	123	4.10
AIM-9M	Sidewinder	Mod	69	134	1.94
AIM-54A	Phoenix	New	45	37	0.82
AIM-54C	Phoenix	Mod	30	45	1.50
AIM-120A	AMRAAM	New	169	111	0.66
FIM-92A	Stinger-Basic	New	222	179	0.81
FIM-92A	Stinger POST/RMP	Mod	29	29	1.00
AGM-65D/F/G	IIR Maverick	Mod	35	33	0.94
A/R/UGM-84A/C/D	Harpoon	New	52	52	1.00
AGM-88A	HARM	New	99	99	1.00
AGM-114A/B	Hellfire	New	241	229	0.95
BGM-71A	TOW I	New	467	472	1.01
BGM-71D	TOW II	Mod	113	113	1.00
–	MLRS-M77	New	654	470	0.72
M-712	Copperhead CLGP	New	408	320	0.78
–	5" Deadeye SALGP	New	218	141	0.65
Low			29	29	0.65
High			654	472	4.10
Mean			158	148	1.31

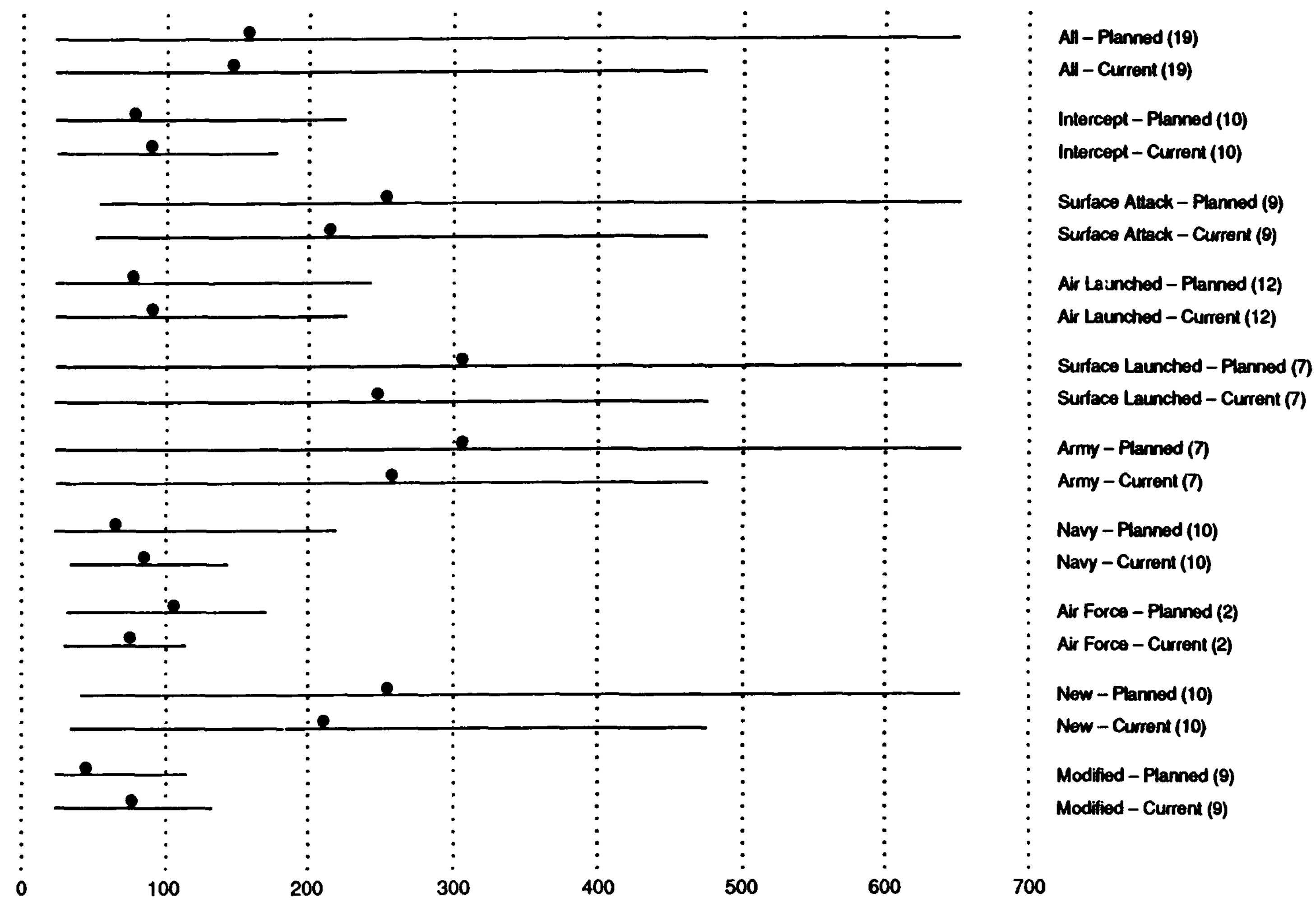
POST/RMP shows no increase in the number of test articles over the development estimate. However, it is possible that the number of test articles for both the AMRAAM and the Stinger-POST/RMP could change before development is completed.

The ranges of development ("planned") and current estimates of test article quantities for each category of munition are shown in Figure IV-7.[14] The patterns in the figure result primarily from two causes. The first cause is the large development estimates of test article quantities, and somewhat smaller (although still large) current estimates of test article quantities, for new Army surface attack, surface-launched munitions. The average numbers of test articles for these categories of munitions are more than double the average number of test articles for the corresponding categories. The second cause is that the current estimates of test article quantities for modifications of Navy air-launched intercept munitions were in all cases as high or much higher than the development estimates because of optimistic initial assessments of the technical difficulties. This caused the average current estimates of test article quantities to be higher than the development estimates for the intercept, air-launched, Navy, and modified munitions categories.

These patterns are reflected in the ranges of development quantity growth factors for each category of munition, as shown in Figure IV-8.[15] The development quantity growth factors are significantly greater for air-launched and modified munitions than for surface-launched and new munitions, respectively. While the ranges of development quantity growth factors are higher for intercept and Navy munitions as compared to surface attack, and Army and Air Force munitions, respectively, those differences are not statistically significant.

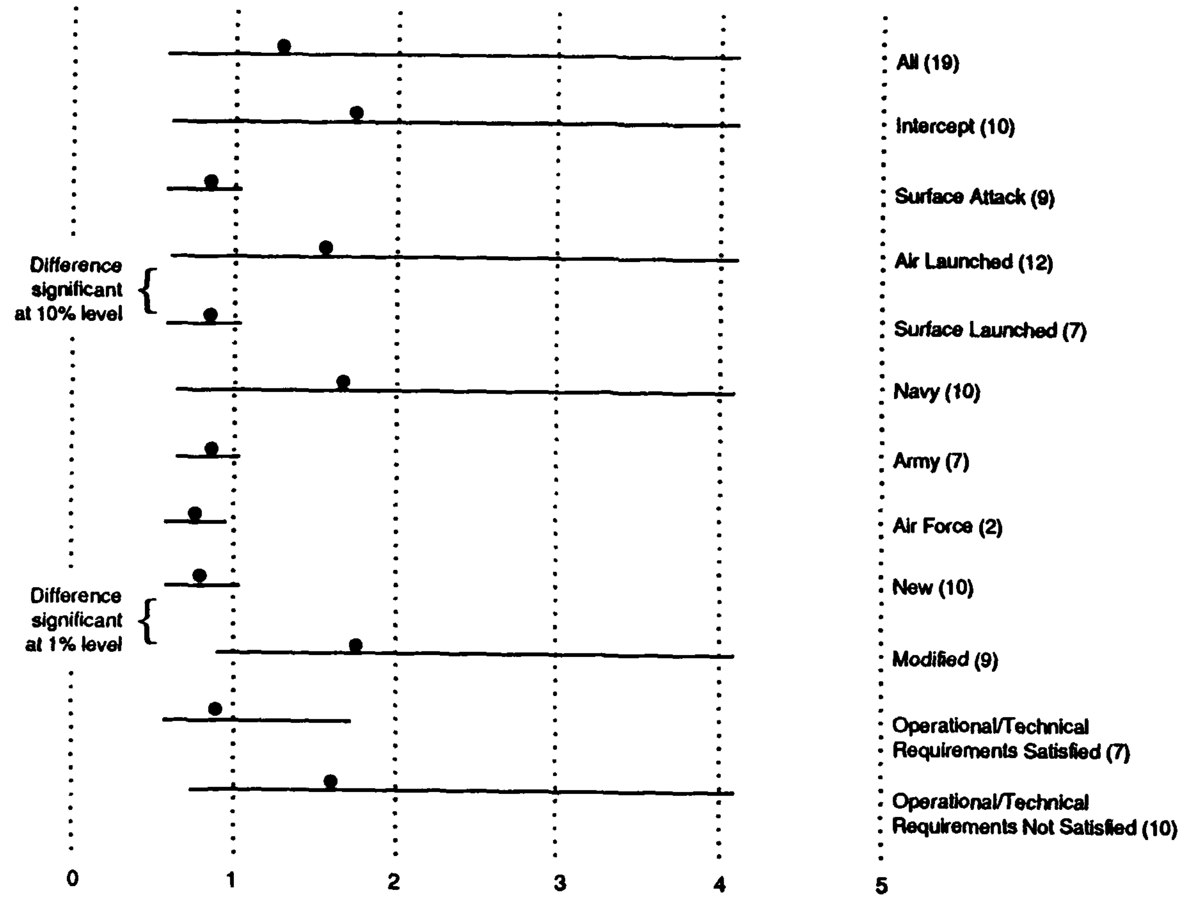
Technical problems resulting in development schedule growth did not necessarily result in development quantity growth. Development quantity growth factors were not significantly correlated with development schedule growth factors, even when the sample is divided into new and modified munitions.[16] However, development quantity growth was lower for the more recently developed munitions.

The extent of development quantity growth was significantly related to the applicability of several of the acquisition policies, as shown in Figure IV-9.[17] The range of development quantity growth factors was lower for munitions with independent cost estimates than for those without. The range of development quantity growth factors was also significantly lower for munitions with advanced development phases, whether with or



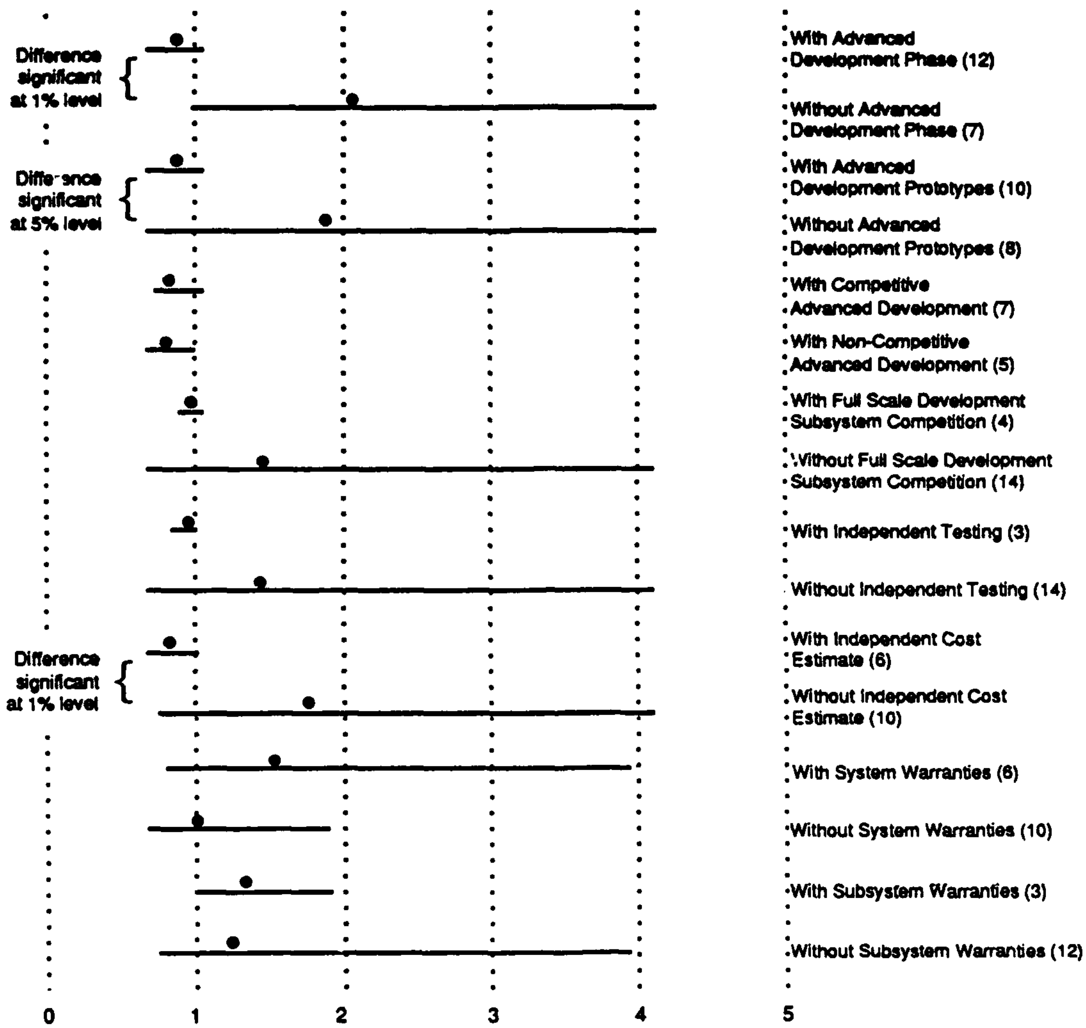
Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-7. Ranges of Planned and Current Estimates of Numbers of Test Articles for Each Category of Munition



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-8. Range of Development Quantity Growth Factors for Each Category of Munition



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-9. Range of Development Quantity Growth Factors for Applications of Each Acquisition Policy

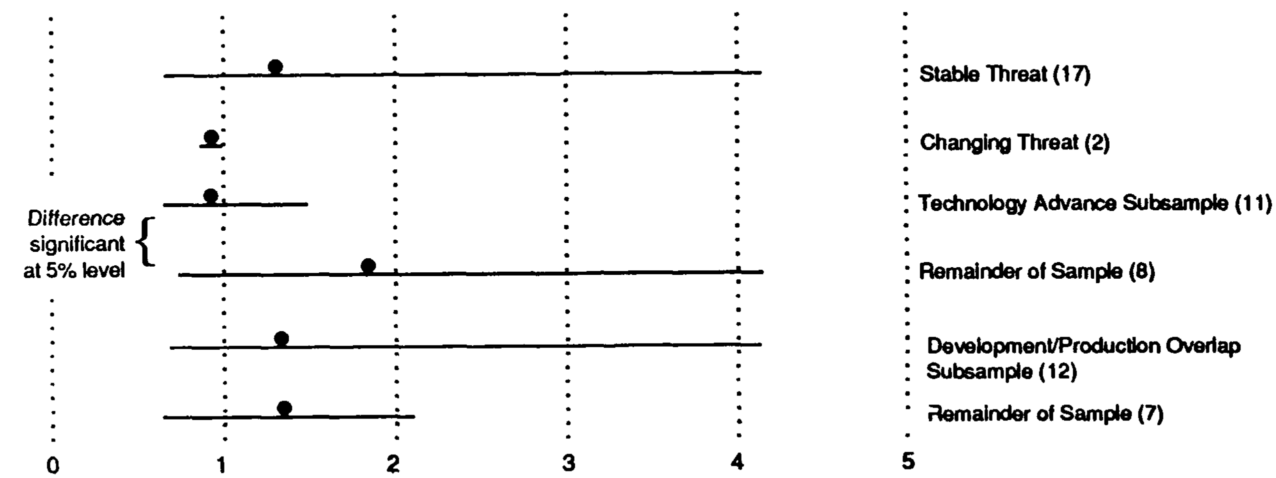
without prototypes. This result is closely related to the differences in development quantity growth factors between new and modified munitions, in that all of the new munitions and only two of the modified munitions had advanced development phases. Optimism about technical problems in the development of modifications may have resulted in the foregoing of advanced development phases as well as underestimates of the numbers of test articles that would be required. Development quantity growth for the modified munitions with advanced development was as low or lower than for any of the modified munitions without advanced development, but the subsample size for modifications was too small to show that the differences are statistically significant.

The extent to which development quantity growth was related to the risks described in Chapter III is shown in Figure IV-10.[18] The two munitions that had substantial changes to the threat during the development phase either had no growth (HARM) or a slight decrease in the numbers of test articles (IIR Maverick). Changes in the threat did not result in any increase in the number of test articles required.

As shown in Figure IV-10, the development quantity growth factors for the technology advance and resource requirements subsample discussed in Chapter III are not representative of the total sample. Because of the differences between this subsample and the remainder of the sample, no valid inferences could be drawn for the entire sample about relationships between development quantity growth and the required levels of technological advance or percentage requirements for new resources.

Development quantity growth was not correlated with the development/production overlap ratios discussed in the previous chapter.[19]

The number of test articles was inversely related to the average cost of the test articles. Log-linear relationships for both new and modified munitions are shown in Figure IV-11.[20] The more complex and expensive new munitions had smaller numbers of test articles, while less expensive munitions such as TOW and MLRS had relatively larger numbers of test articles. The relationship does not appear to be as strong for modification programs. What is not apparent is whether or not more simulation work was done with the more expensive munitions in order to compensate for the fewer numbers of test articles.



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-10. Range of Development Quantity Growth Factors for Each Category of Program Risk

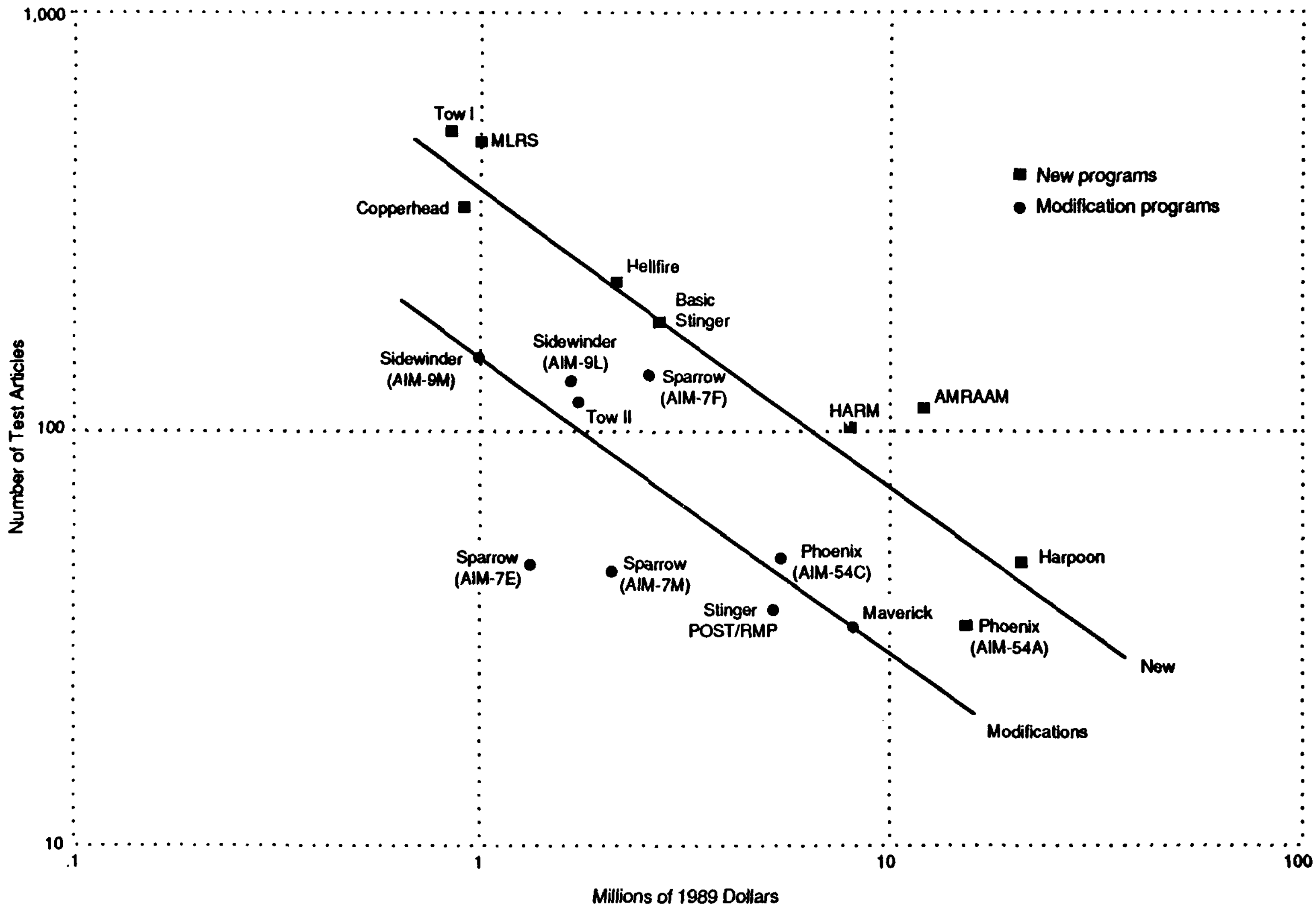


Figure IV-11. Cost Per Test Article

D. DEVELOPMENT COST GROWTH

The development and current estimates of development costs, and the development cost growth factors are shown in Table IV-7. All of the cost estimates have been escalated to 1989 dollars.[21] The development cost growth factor is defined as the current estimate shown in the latest SAR divided by the development estimate shown in the SAR at the time of Milestone II approval. For those munitions for which no Milestone II dates appear in the SARs, growth factors were based on the start of full scale development.

Two of the munitions in the sample have not completed development: the AMRAAM and the Stinger-POST/RMP. The development cost growth factors for those two munitions will continue to increase, above the latest values of 1.50 and 1.02, respectively, until development is completed. For the remainder of the munitions in the sample, the current estimates are the actual development costs.

The ranges of development and current estimates for each category of munition are shown in Figure IV-12.[22] For each category, the average of the current estimates is higher than the average of the development estimates. While the average for the Air Force munitions is more than twice as high as for the Army and Navy munitions, this is due to the highest development cost munition (the AMRAAM) being included in a sample size of two.

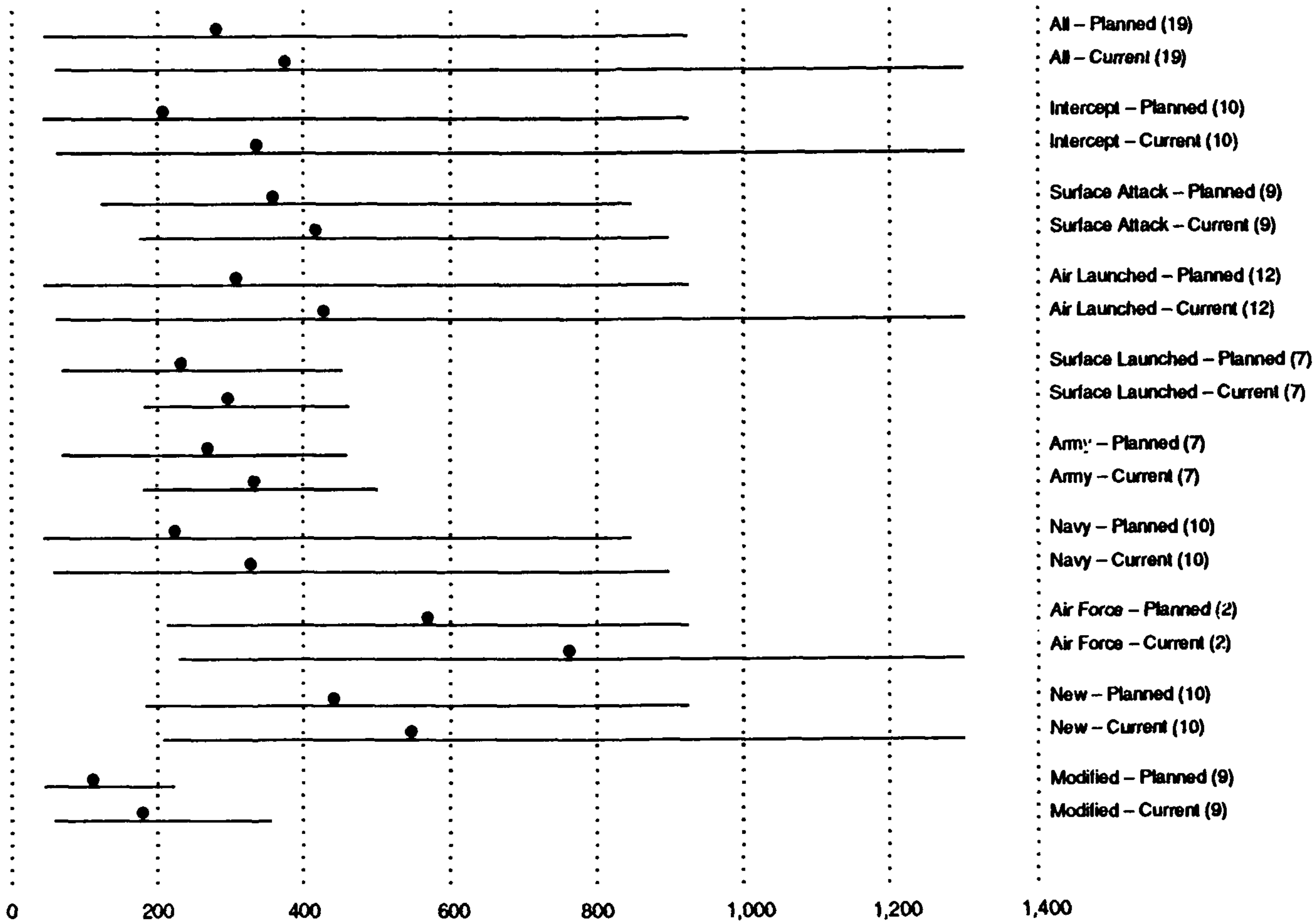
The average development cost for new munitions was over twice that for modified munitions, and little overlap was apparent between the ranges of development costs. Even with substantial cost growth, the development costs for modifications tended to be much lower than for new munitions.

Ranges of development cost growth factors for each category of munition are shown in Figure IV-13.[23] Cost growth for intercept munitions was significantly higher than for surface attack munitions, primarily due to the AIM-7F Sparrow and both of the AIM-9 Sidewinder modifications. For the same reason, the average development cost growth was higher for the modified and air-launched munitions categories, although the differences between those and the new and surface-launched munition categories, respectively, were not statistically significant.

It should not be surprising, then, that development cost growth and development quantity growth were directly correlated for the total sample and for the air-launched and

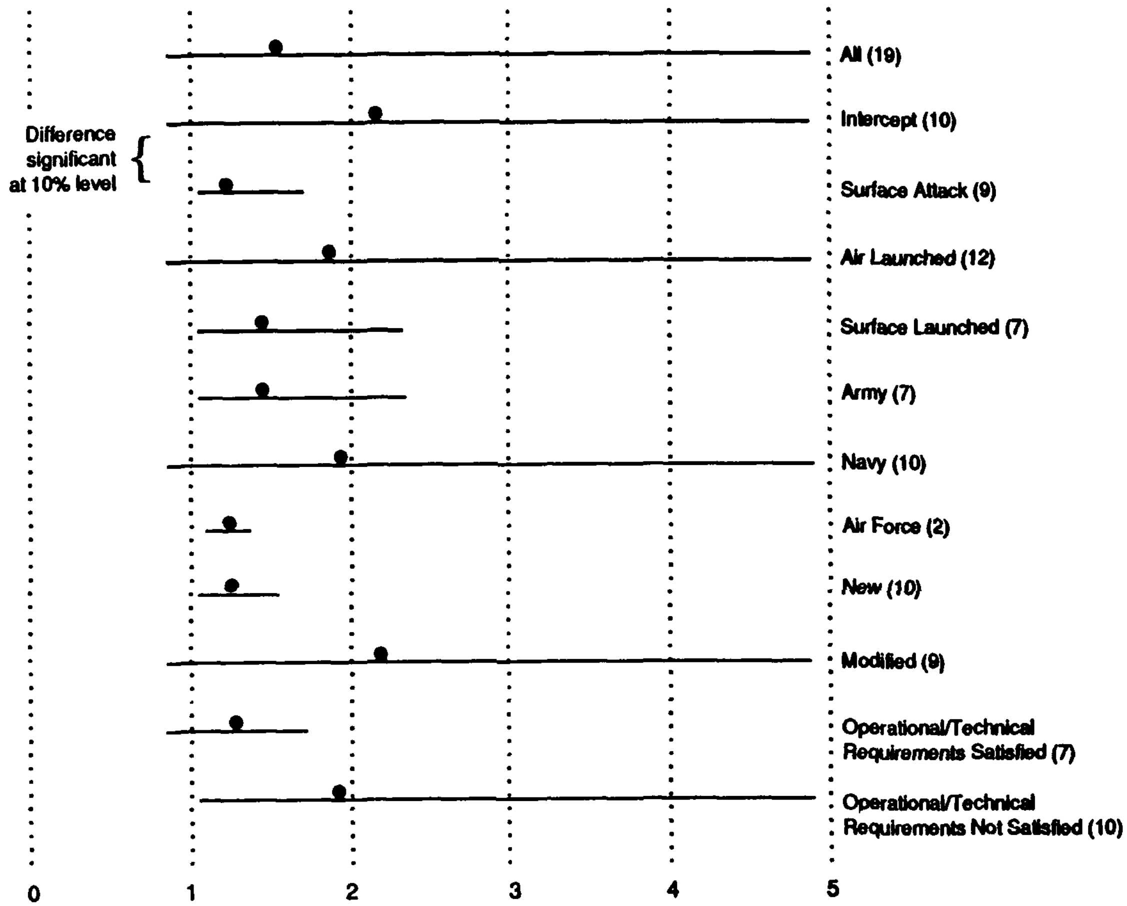
Table IV-7. Development Costs and Development Cost Growth Factors

Designator	Title	New/Mod	Development Estimate of Development Cost (1989$ Millions)	Current Estimate of Development Cost (1989$ Millions)	Development Cost Growth Factor
A/RIM-7E	Sparrow III B CW	Mod	74.1	62.1	0.84
AIM-7F	Sparrow III Pulse Doppler	Mod	83.5	356.3	4.27
A/RIM 7M	Sparrow III Monopulse	Mod	96.1	94.0	0.98
AIM-9L	Sidewinder	Mod	40.0	195.4	4.89
AIM-9M	Sidewinder	Mod	65.7	134.2	2.04
AIM-54A	Phoenix	New	359.7	552.1	1.54
AIM-54C	Phoenix	Mod	140.8	234.9	1.67
AIM-120A	AMRAAM	New	927.0	1,299.9	1.40
FIM-92A	Stinger-Basic	New	217.5	317.2	1.46
FIM-92A	Stinger-POST/RMP	Mod	77.7	182.2	2.34
AGM-65D/F/G	IIR Maverick	Mod	221.9	236.7	1.07
A/R/UGM-84A/C/D	Harpoon	New	846.0	895.8	1.06
AGM-88A	HARM	New	399.9	569.2	1.42
AGM-114A/B	Hellfire	New	463.0	506.8	1.09
BGM-71A	TOW I	New	351.4	422.5	1.20
BGM-71D	TOW II	Mod	105.6	179.6	1.70
–	MLRS-M77	New	454.3	466.0	1.03
M-712	Copperhead CLGP	New	231.0	296.4	1.28
–	5" Deadeye SALGP	New	180.3	209.7	1.16
Low			40.0	62.1	0.84
High			927.0	1,299.9	4.89
Mean			280.8	379.5	1.71



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-12. Ranges of Planned and Current Estimates of Development Costs for Each Category of Munition



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

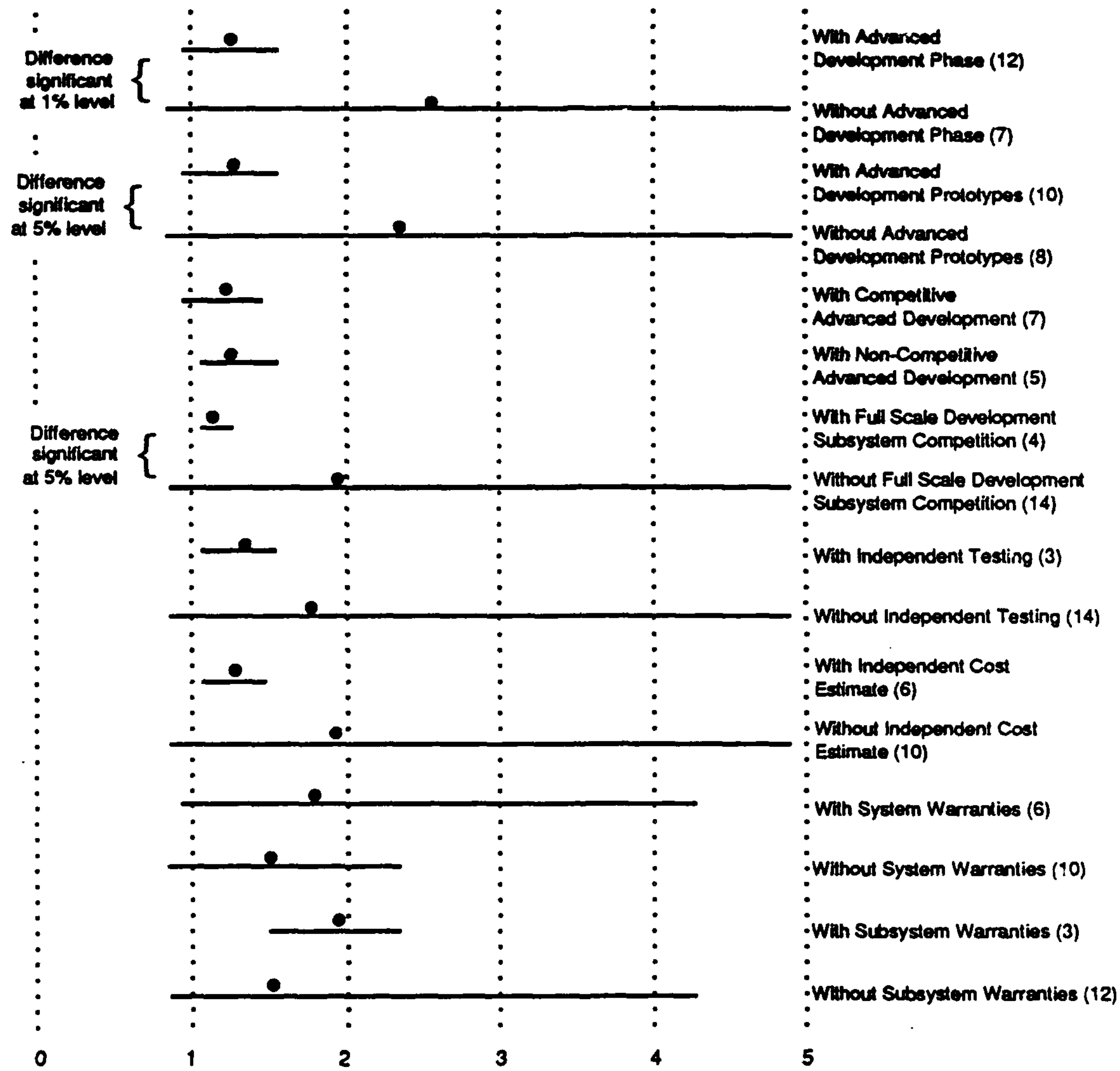
Figure IV-13. Range of Development Cost Growth Factors for Each Category of Munition

modified categories.[24] These correlations largely result from the high development cost growth and high development quantity growth for four of the six Navy air-launched intercept missile modifications (AIM-7F Sparrow, AIM-9L and AIM-9M Sidewinder, and AIM-54C Phoenix).

Surprisingly, development cost growth was not related to development schedule growth, for the entire sample, new munitions, or modified munitions. Nor was any relationship detected between development cost growth and full scale development start date.[25]

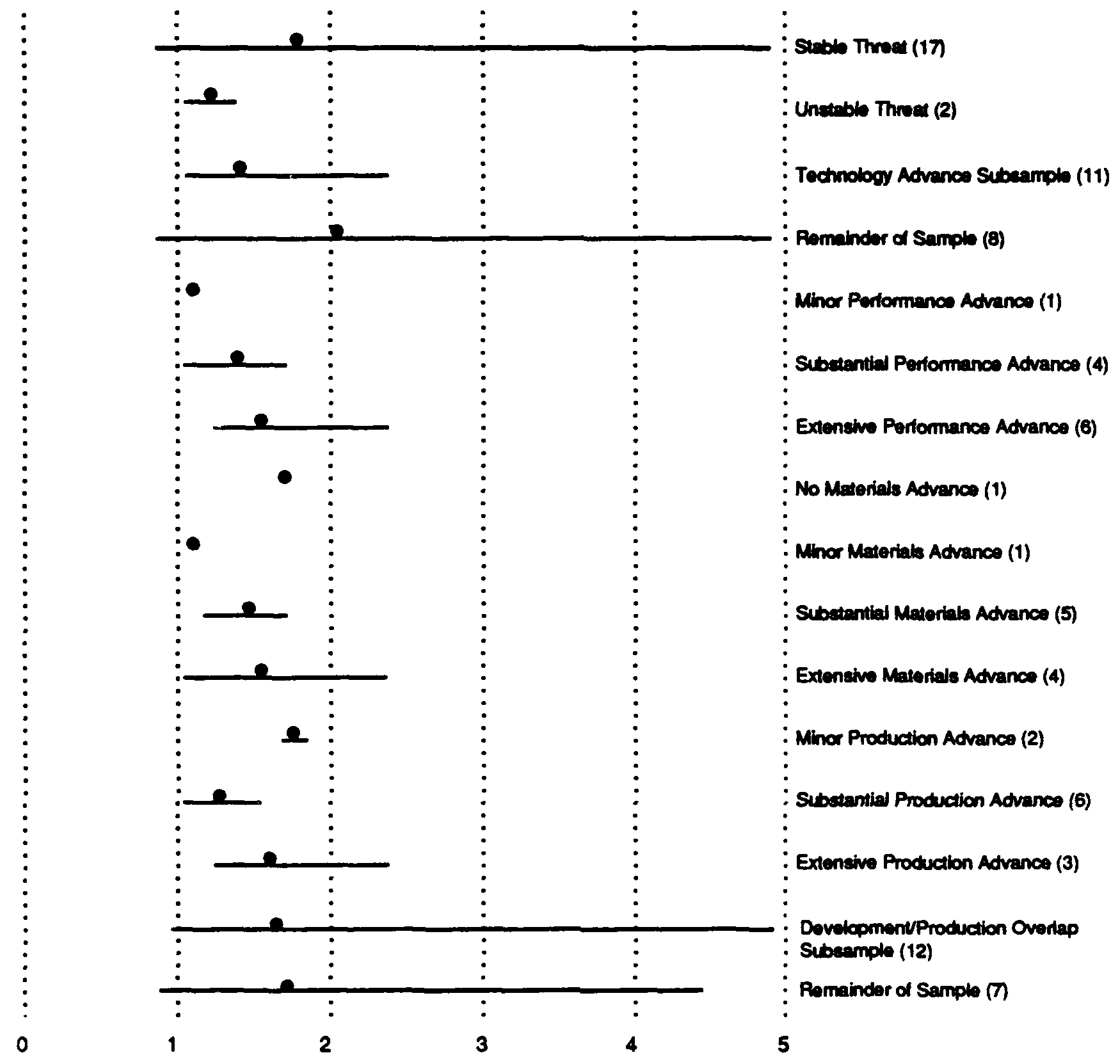
The extent of development cost growth was significantly related to the application of several of the acquisition policies, as shown in Figure IV-14.[26] As was the case with development quantity growth, development cost growth was significantly lower for munitions with advanced development phases. Again, this result is closely related to the differences in development cost growth between new and modified munitions, in that all of the new munitions, but only two of the modified munitions underwent advanced development. The average of the development cost growth factors for the modified munitions with advanced development phases was less than half of the average of the development cost growth factors for the modified munitions without advanced development phases; however, the sample size for modifications was too small to show that the differences are statistically significant. Whether or not advanced development was competitive made no difference, but development cost growth was significantly lower for munitions with competitive full scale development at the subsystem level.

The extent to which development cost growth was related to the risks described in Chapter III is shown in Figure IV-15.[27] For the two munitions that had substantial changes to the threat during the development phase (IIR Maverick and HARM), the effects of threat instability on development cost growth were ambiguous. The IIR Maverick had the third lowest development cost growth among both the nine surface attack munitions and the nine modifications, and the fourth lowest development cost growth among the twelve air-launched munitions. The HARM had the second highest development cost growth among the nine surface attack munitions, the sixth highest among the twelve air-launched munitions, and the third highest among the ten new munitions. The difference in development cost growth between these two munitions suggests that changes to the threat need not always result in high development cost growth.



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-14. Range of Development Cost Growth Factors for Applications of Each Acquisition Policy



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-15. Range of Development Cost Growth Factors for Each Category of Program Risk

Development cost growth was not related to the required levels of technological advance for performance, materials, or production processes, as shown in Figure IV-15. Higher technological risks do not necessarily result in higher development cost growth. Development cost growth was inversely correlated with the percentage requirements for new test equipment, facilities, and tooling, but only the correlation with facilities is statistically significant.[28] Higher development cost growth may result in lower expenditures on facilities.

Development cost growth was not affected by the extent of overlap between development and production.[29]

E. PRODUCTION COST GROWTH

The estimates of production costs made at the start of development, the current estimates of production costs, what the production costs would be if the development estimate quantity were produced, and the production cost growth factors are shown in Table IV-8.[30] The development estimates of production costs are from the earliest available SARs for the munitions, subsequently escalated from then-year dollars to 1989 dollars. The current estimates are from the latest SARs, also escalated to 1989 dollars. The production cost growth factors are based on estimates of what the production costs would be if the quantity forecast at the time of Milestone II were produced. Those estimates, taken from the individual munition case studies in Volume II, are based on calculations of total procurement (recurring and non-recurring) cost-quantity curve parameters, which are then used to estimate the quantity adjusted production costs. Because of insufficient data, it was not possible to do those calculations for the A/RIM-7E and AIM-7F Sparrow modifications, the AMRAAM, the Stinger-POST/RMP, the TOW I, or the MLRS. Production cost growth factors calculated in this manner were used in the comparisons in order to avoid the distortions to total production costs caused by changes in total production quantities. Total production quantity changes are discussed in the next section of this chapter.

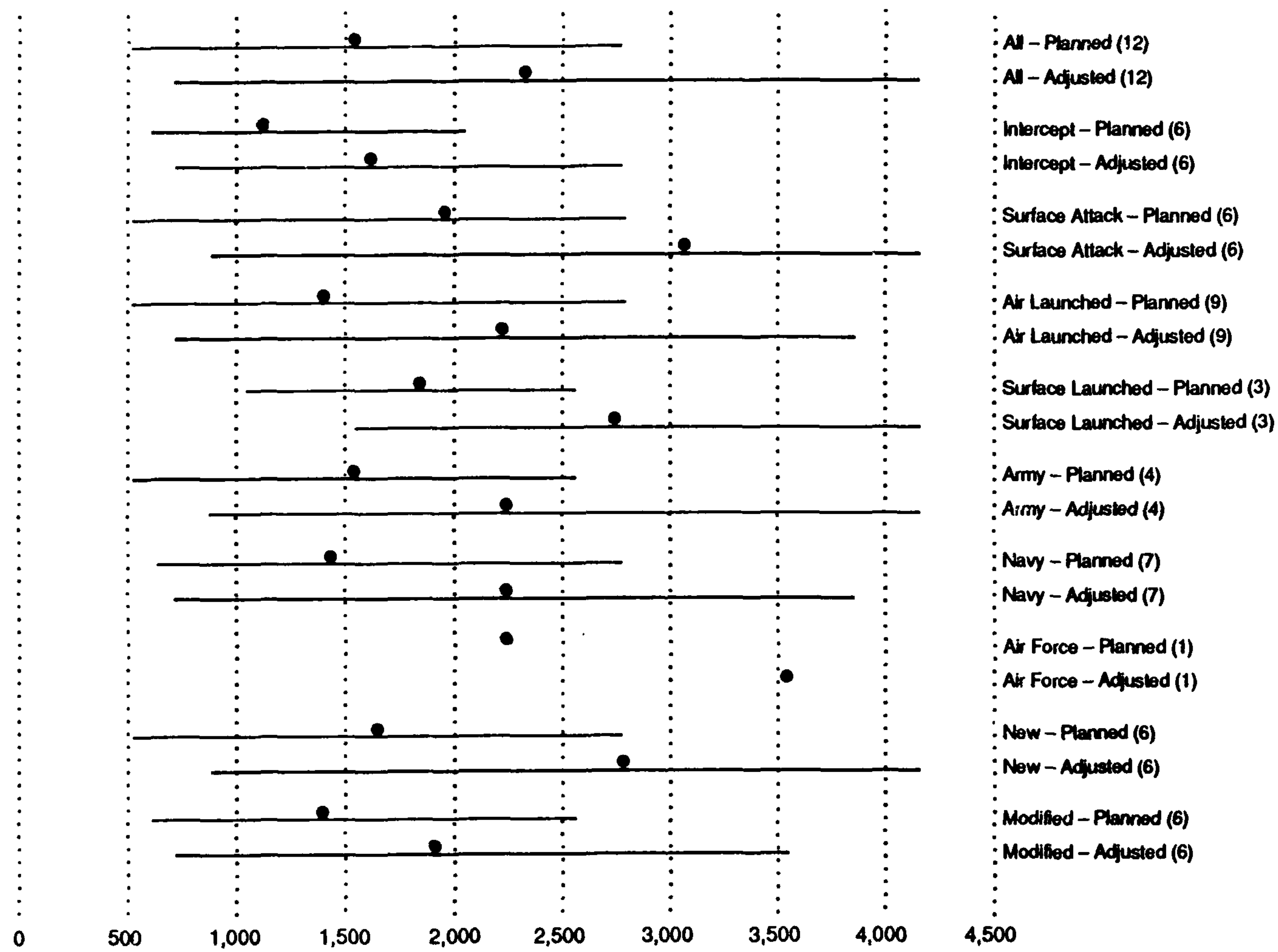
Ranges of the estimates of production costs made at the start of development ("planned") and what the current production costs would be if the development estimate quantity were produced ("adjusted") are shown in Figure IV-16 for each category of munition.[31] For each category, the average of the current total estimates is higher than the average of the originally planned estimates. The average for the surface attack category is almost twice as high as the average for the intercept category. The current average for modifications is approximately two-thirds of the current average for new munitions.

Ranges of the production cost growth factors for each category of munition are shown in Figure IV-17.[32] Production cost growth does not vary significantly between any of the categories. While production cost growth tended to be somewhat higher for new munitions than for modifications, the difference is not statistically significant.

Table IV-8. Development, Current, and Quantity-Adjusted Estimates of Production Costs, and Production Cost Growth Factors

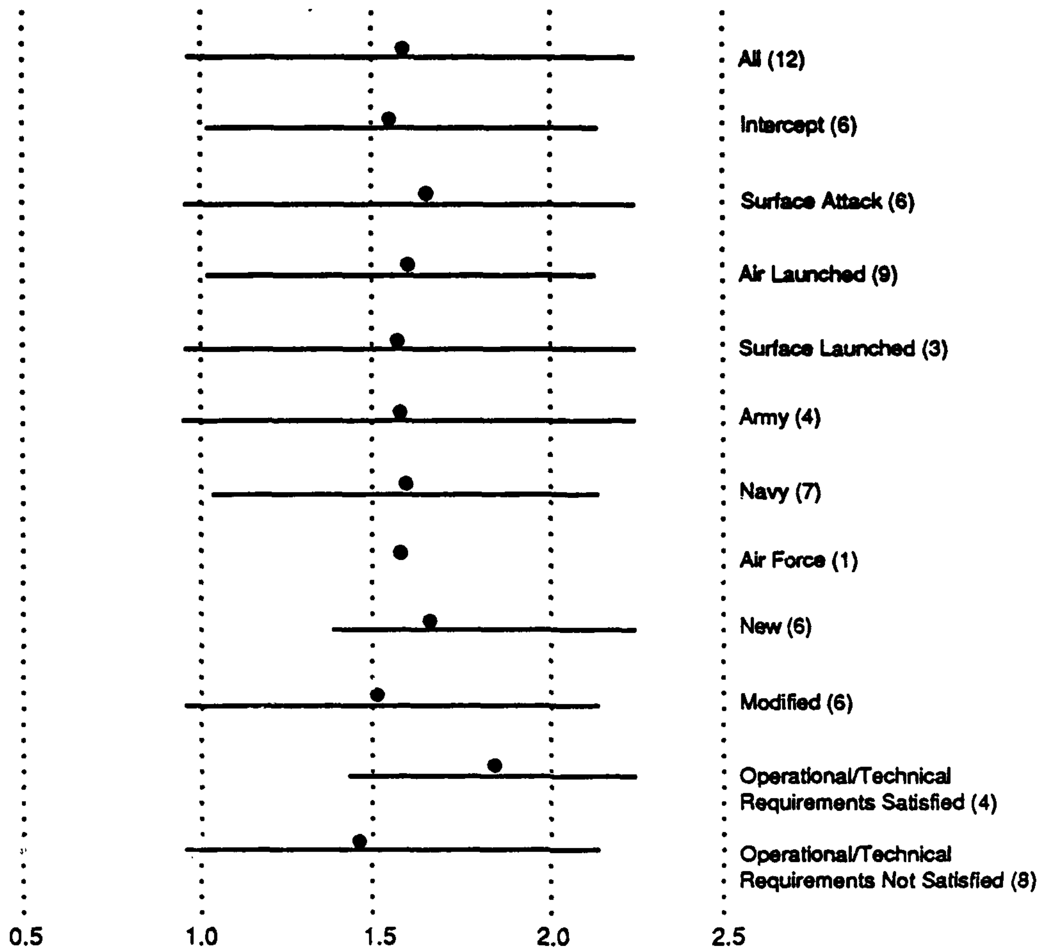
Designator	Title	New/ Mod	Development Estimate of Production Cost (1989$ Milions)	Current Estimate of Production Cost (1989$ Millions)	Quantity Adjusted Estimate of Production Cost (1989$ Millions)	Production Cost Growth Factor
A/RIM-7E	Sparrow III B CW	Mod	4,922.5	2,126.8	I.D.	I.D.
AIM-7F	Sparrow III Pulse Doppler	Mod	1,498.9	3,645.8	I.D.	I.D.
A/RIM-7M	Sparrow III Monopulse	Mod	1,644.1	2,749.0	2,156.0	1.31
AIM-9L	Sidewinder	Mod	655.1	1,609.5	1,391.4	2.12
AIM-9M	Sidewinder	Mod	701.4	1,321.4	709.5	1.01
AIM-54A	Phoenix	New	2,049.2	2,724.6	2,768.0	1.35
AIM-54C	Phoenix	Mod	628.7	3,358.7	1,261.9	2.01
AIM-120A	AMRAAM	New	7,650.4	8,281.2	I.D.	I.D.
FIM-92A	Stinger-Basic	New	1,086.9	2,971.4	1,575.3	1.45
FIM-92A	Stinger-POST/RMP	Mod	I.U.	I.D.	I.D.	I.D.
AGM-65D/F/G	IIR Maverick	Mod	2,240.7	6,539.5	3,531.7	1.58
A/R/UGM -84A/C/D	Harpoon	New	1,845.3	4,639.0	3,566.9	1.93
AGM-88A	HARM	New	2,784.2	4,022.9	3,866.0	1.39
AGM-114A/B	Hellfire	New	510.1	1,347.3	819.5	1.61
BGM-71A	TOW I	New	2,665.5	3,025.4	I.D.	I.D.
BGM-71D	TOW II	Mod	2,553.1	2,434.7	2,449.2	0.96
–	MLRS	New	3,782.4	4,345,0	I.D.	I.D.
M-712	Copperhead CLGP	New	1,857.8	1,447.2	4,150.9	2.23
–	5" Deadeye SALGP	New	539.8*	Cancelled	Cancelled	Cancelled
Low			510.1	1,321.4	709.5	0.96
High			7,650.4	8,281.2	4,150.9	2.23
Mean			2,298.6	3,328.8	2,353.9	1.58
Mean for Quantity Adjusted Sample			1,546.4	2,930.4	2,353.9	1.58

I.U. - Information unavailable.
I.D. - Insufficient data for estimation of cost curve.
* - Excluded from the mean calculation because of subsequent cancellation.



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-16. Ranges of Planned and Adjusted Estimates of Production Costs for Each Category of Munition



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

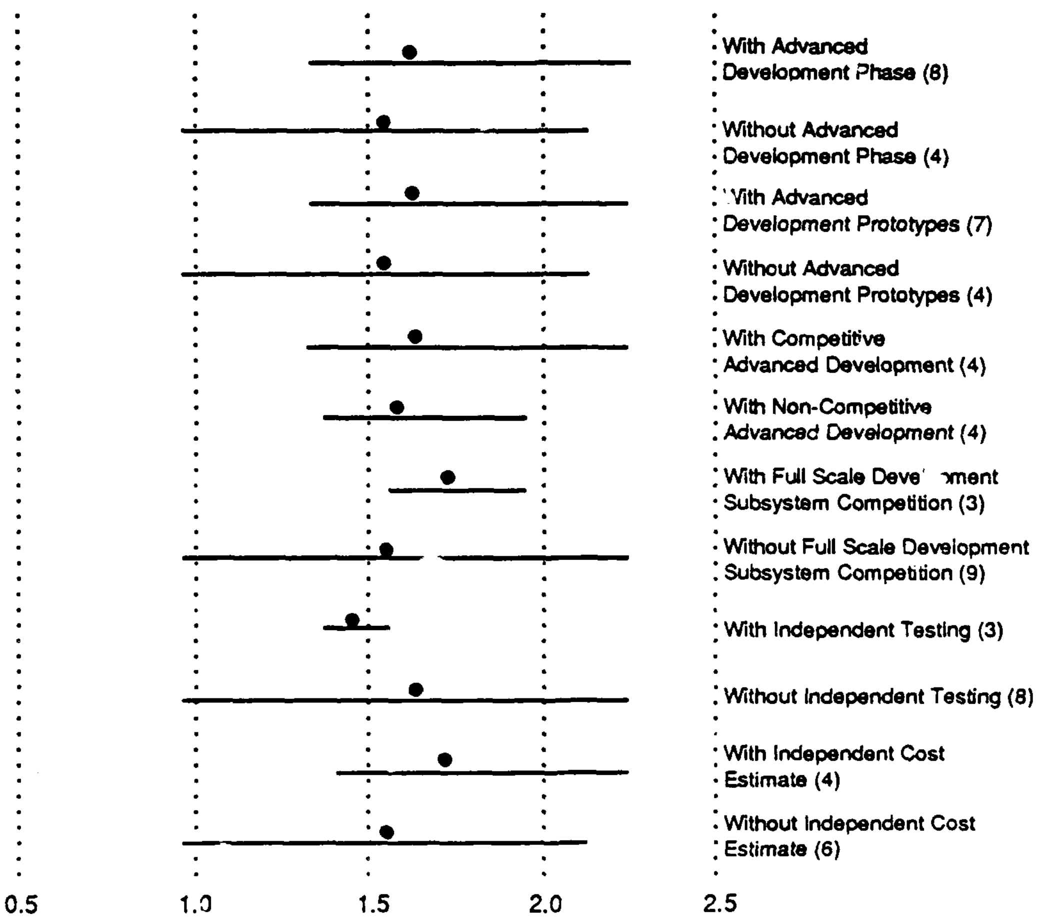
Figure IV-17. Range of Production Cost Growth Factors for Each Category of Munition

Higher production cost growth was directly related to higher development schedule growth.[33] Slippage in the development schedule involved problems that also affected producibility for several of the munitions in the sample, as discussed in the case studies in Volume II for the AIM-9L Sidewinder and the Copperhead.

However, production cost growth was not related to development quantity growth or to development cost growth, nor did production cost growth show any significant improvement over time for the munitions in the sample.[34]

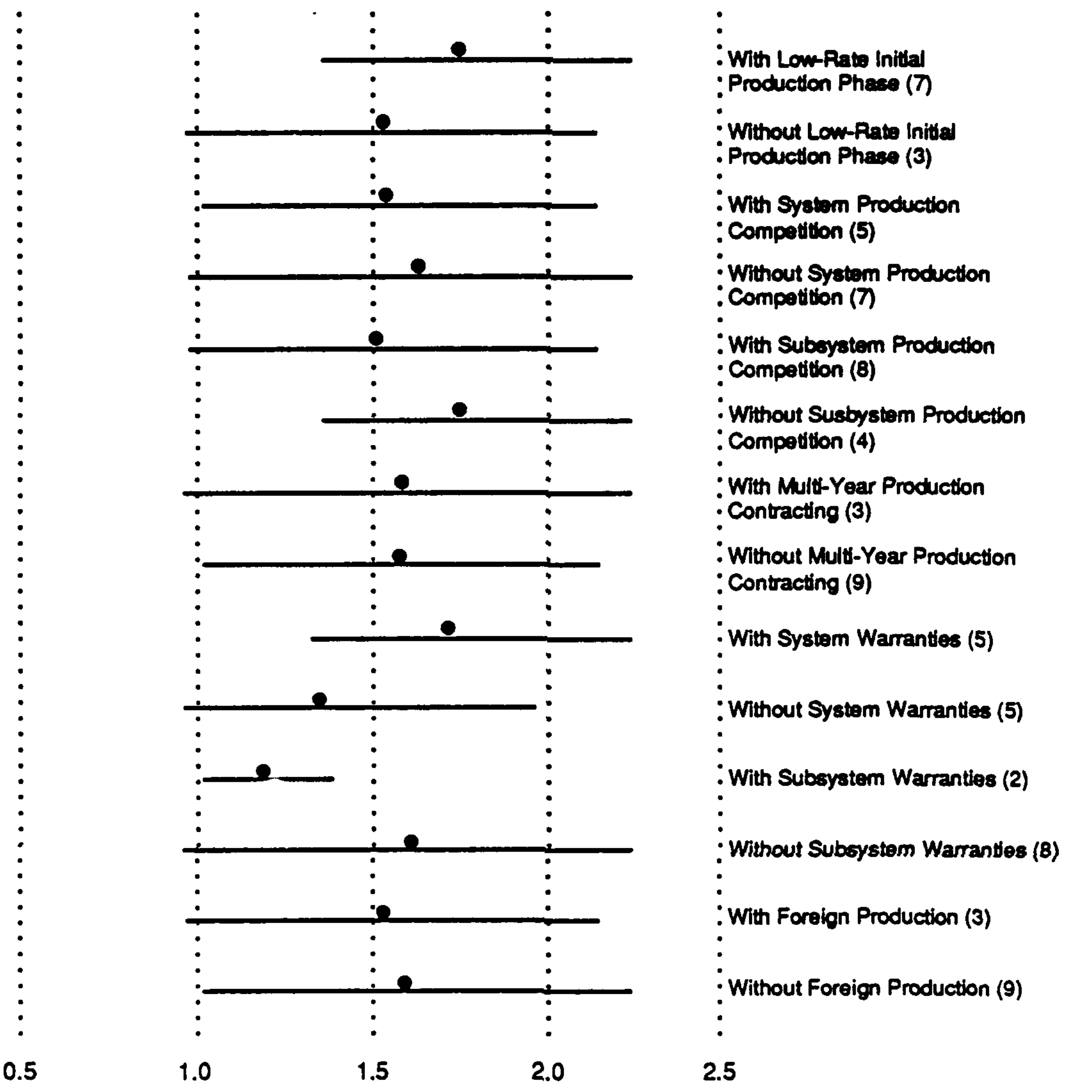
Production cost growth was not significantly related to the application during the development and production phases of any of the acquisition policies. None of the

differences shown in Figure IV-18 are statistically significant.[35] In particular, multi-year contracting and production competition had no apparent effects on production cost growth. Nor did any of the initiatives during the development phase, such as advanced development prototypes, independent cost estimates, or independent testing, significantly reduce the uncertainties as to what production costs would be. During the development phase, efforts were focused primarily on development of operational munitions without much attention to either the producibility of the munitions or the development and testing of the production processes, as discussed in the case studies in Volume II for the AIM-7E Sparrow, AIM-54 Phoenix, Harpoon, HARM, Copperhead, and 5" Deadeye SALGP.



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

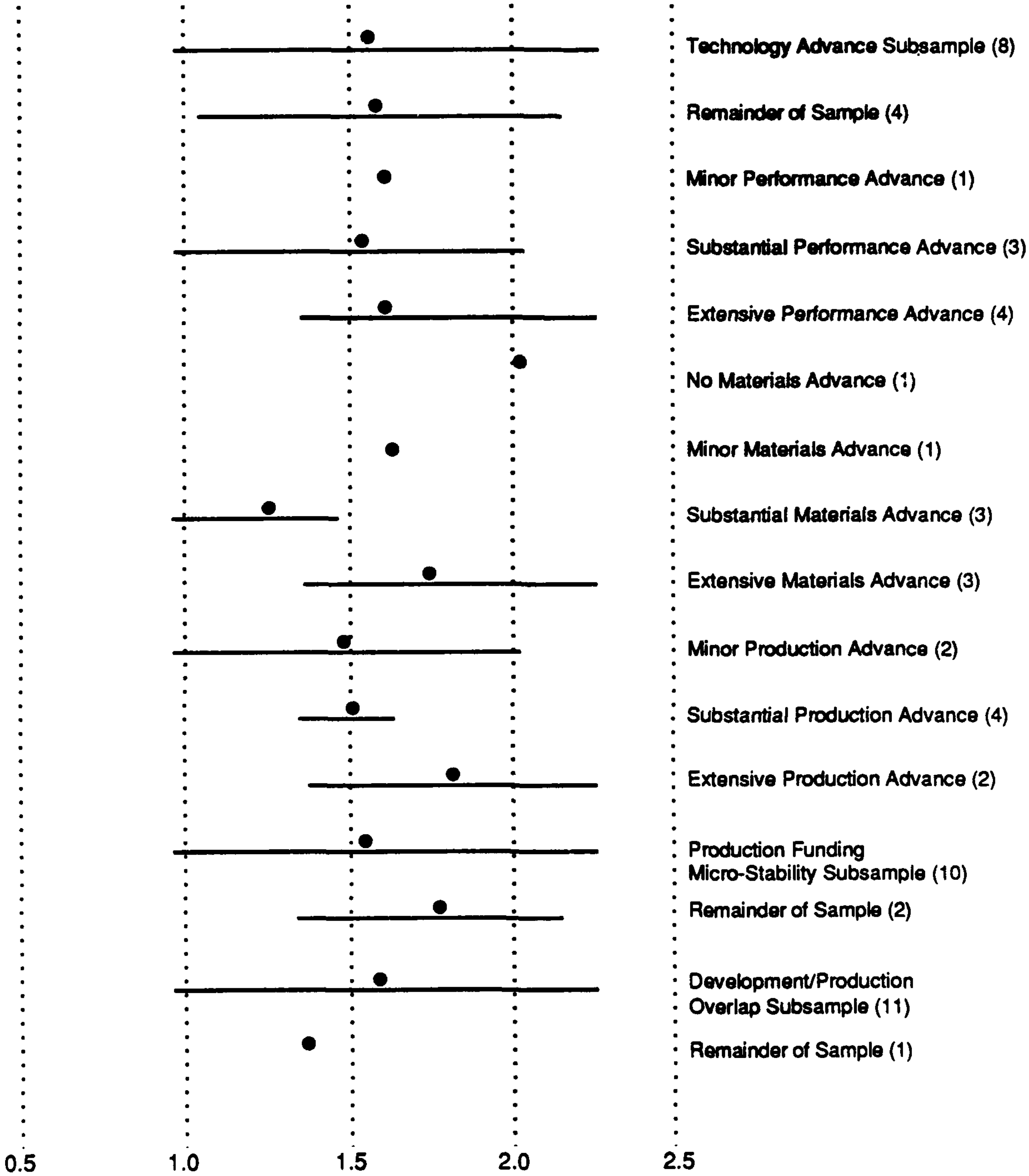
Figure IV-18. Range of Production Cost Growth Factors for Applications of Each Acquisition Policy



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-18. Range of Production Cost Growth Factors for Applications of Each Acquisition Policy (Continued)

The extent to which production cost growth was related to the risks described in Chapter III is shown in Figure IV-19.[36] Production cost growth was not related to the required levels of technological advance for performance, materials, or production processes. Higher technological risks did not necessarily result in higher production cost growth. Furthermore, production cost growth was not significantly related to the percentage requirements for new test equipment, facilities, or tooling.[37]



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-19. Range of Production Cost Growth Factors for Each Category of Program Risk

Production cost growth was directly related to the production funding macro-stability measure discussed in the previous chapter. Higher overall defense procurement TOA growth rates were accompanied by higher production cost growth. However, production cost growth was not significantly affected by differences between the funding levels in the congressional appropriations and the presidential budgets (the procurement funding micro-stability measure described in Chapter III).[38] Production cost growth was directly correlated to the extent of the overlap between development and production: the greater the overlap, the greater the production cost growth.[39]

F. PRODUCTION QUANTITY GROWTH

The development estimates and the current estimates of (or actual) production quantities, and the production quantity growth factors are shown in Table IV-9. The 5" Deadeye SLGP is excluded from the sample because the program was cancelled before it entered production. The production quantity growth factor for a munition is defined as the current estimate of the total production quantity from the most recent SAR divided by the development estimate as of Milestone II. A production quantity growth factor was not calculated for the AMRAAM because of uncertainty about the currently planned production quantity.

Ranges of the estimates of total production quantities made at the start of development, and the current estimates of production quantities, are shown in Figure IV-20 for each category of munition.[40] The patterns in Figure IV-20 reflect the very large development and current estimates of the production quantities of the Army TOW I, TOW II, and MLRS surface-launched, surface attack munitions.

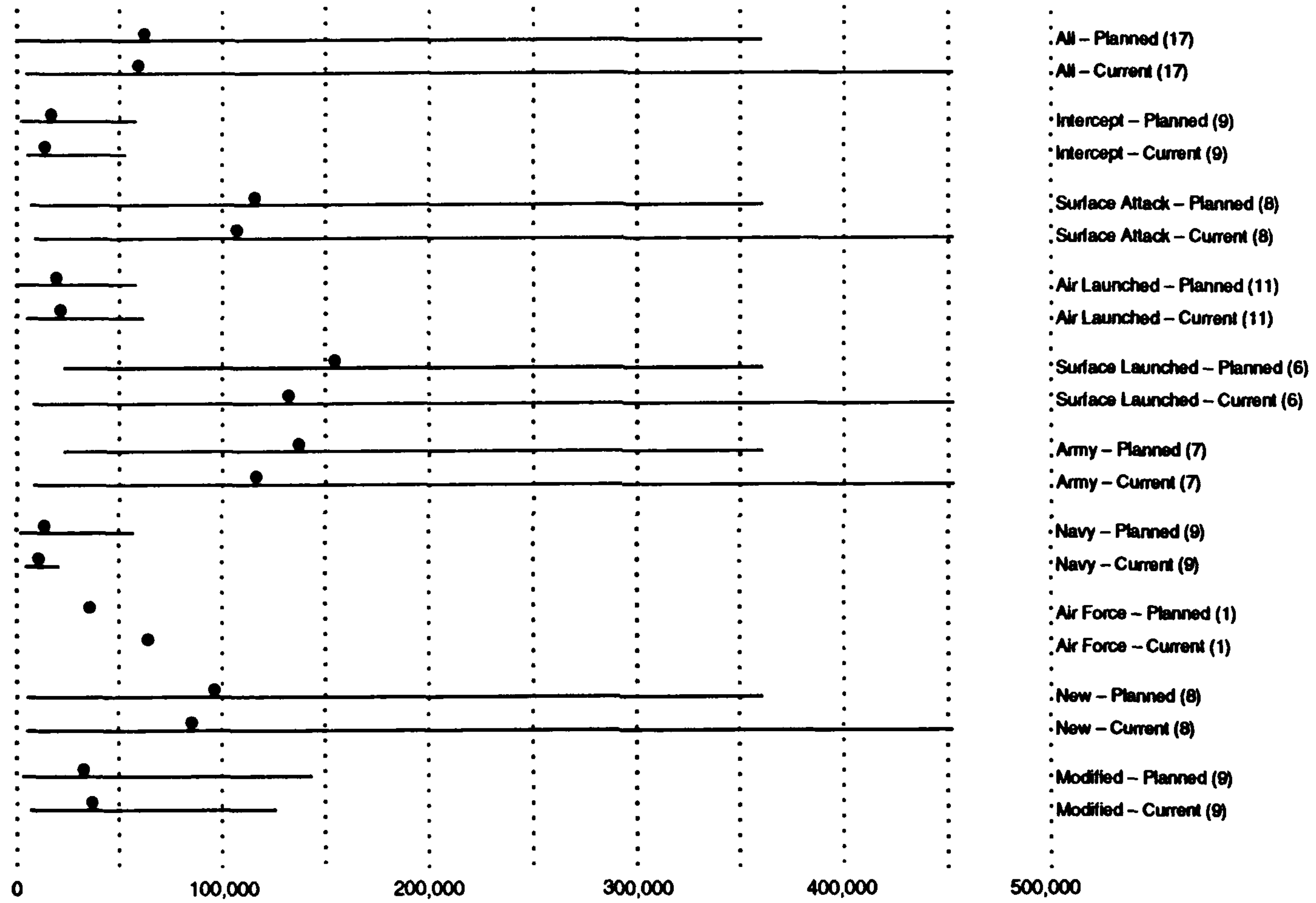
The ranges of production quantity growth factors for each category of munition are shown in Figure IV-21.[41] Production quantity growth did not vary significantly between any of the categories. The wide range in production quantity growth factors for most of the categories suggests that not too much credence should be given the originally planned estimates of total production quantities.

Production quantity growth did not vary significantly between munitions whose operational and technical requirements were satisfied and munitions for which those requirements were not totally satisfied, as shown in Figure IV-21. The fact that production quantities were increased for eight of the ten munitions that did not totally satisfy those requirements suggests that the requirements may have been unduly stringent.

Table IV-9. Production Quantities and Production Quantity Growth Factors

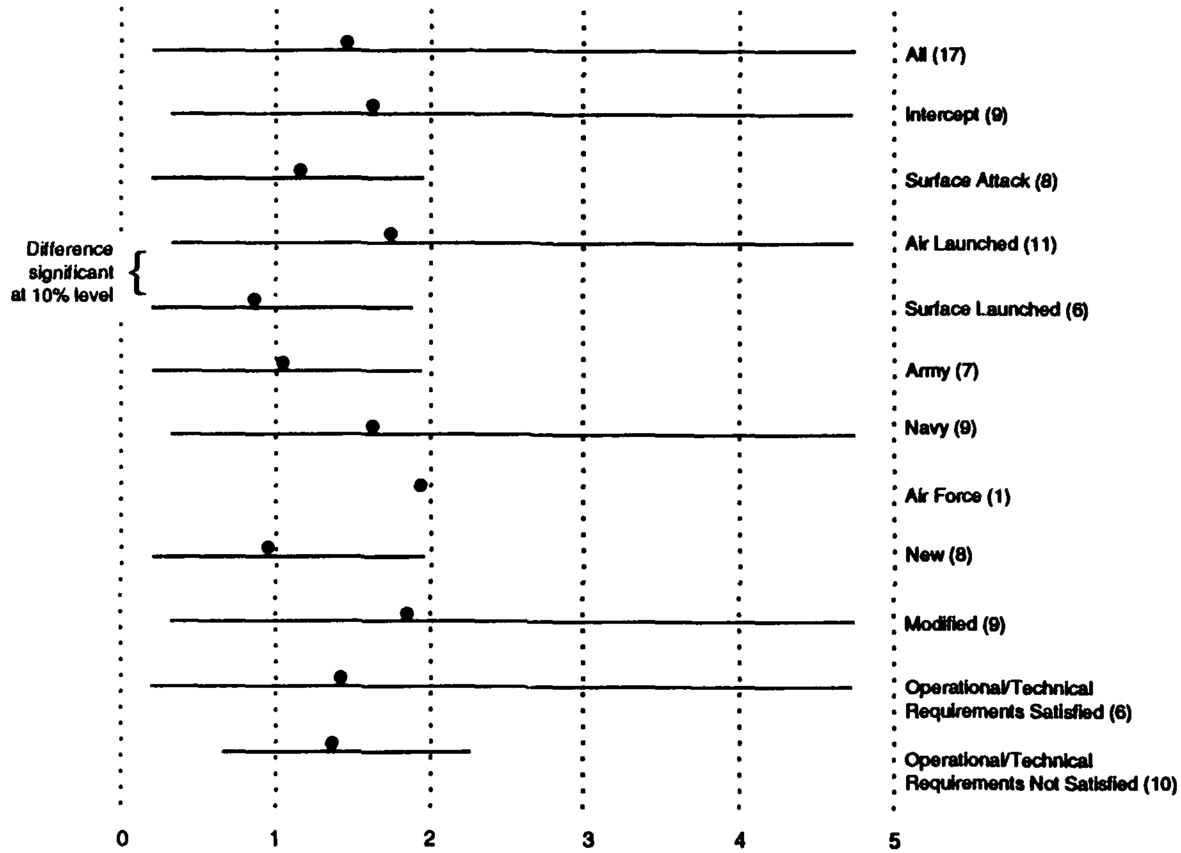
Designator	Title	New/ Mod	Development Estimate of Production Quantity	Current Estimate of Production Quantity	Production Quantity Growth Factor
A/RIM-7E	Sparrow III B CW	Mod	57,773	19,661	0.34
AIM-7F	Sparrow III Pulse Doppler	Mod	9,725	16,145	1.66
A/RIM-7M	Sparrow III Monopulse	Mod	11,095	15,274	1.34
AIM-9L	Sidewinder	Mod	9,258	11,350	1.23
AIM-9M	Sidewinder	Mod	7,450	16,937	2.27
AIM-54A	Phoenix	New	2,339	2,285	0.98
AIM-54C	Phoenix	Mod	705	3,356	4.76
AIM-120A	AMRAAM	New	24,335*	I.U.	I.U.
FIM-92A	Stinger-Basic	New	22,980	8,085	0.35
FIM-92	Stinger POST/RMP	Mod	22,387	42,555	1.90
AGM-65D/F/G	IIR Maverick	Mod	31,078	60,664	1.95
A/R/UGM-84A/C/D	Harpoon	New	2,870	3,971	1.38
AGM-88A	HARM	New	13,754	14,438	1.05
AGM-114A/B	Hellfire	New	24,600	48,696	1.98
BGM-71A	TC[illegible]	New	232,614	137,275	0.59
BGM-71D	TOW [illegible]	Mod	141,224	125,856	0.89
–	MLRS-M77	New	362,832	452,322	1.25
M-712	Copperhead CLGP	New	132,650	24,546	0.19
Low			705	2,285	0.19
High			362,832	452,000	4.76
Mean			63,843	[illegible]9,042	1.42

I.U. - Information unavailable.
* - Excluded from calculation of mean.



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-20. Ranges of Planned and Current Estimates of Production Quantities for Each Category of Munition



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-21. Range of Production Quantity Growth Factors for Each Category of Munition

Production quantity growth had no relationship to production cost growth for the munitions in the sample. A munition with high production cost growth was as likely to have high production quantity growth as was a munition with low production cost growth.[42]

Furthermore, the success of the development program, as measured by development schedule growth or development cost growth had little or no measurable impact on production quantity growth. These results are to be expected, in that once a munition has been fully developed, the total production quantities will be dictated by projected combat requirements, and the perceived requirements themselves may change over time. These requirements were increased over time, as shown by a significant direct relationship between production start dates and production quantity growth factors.[43]

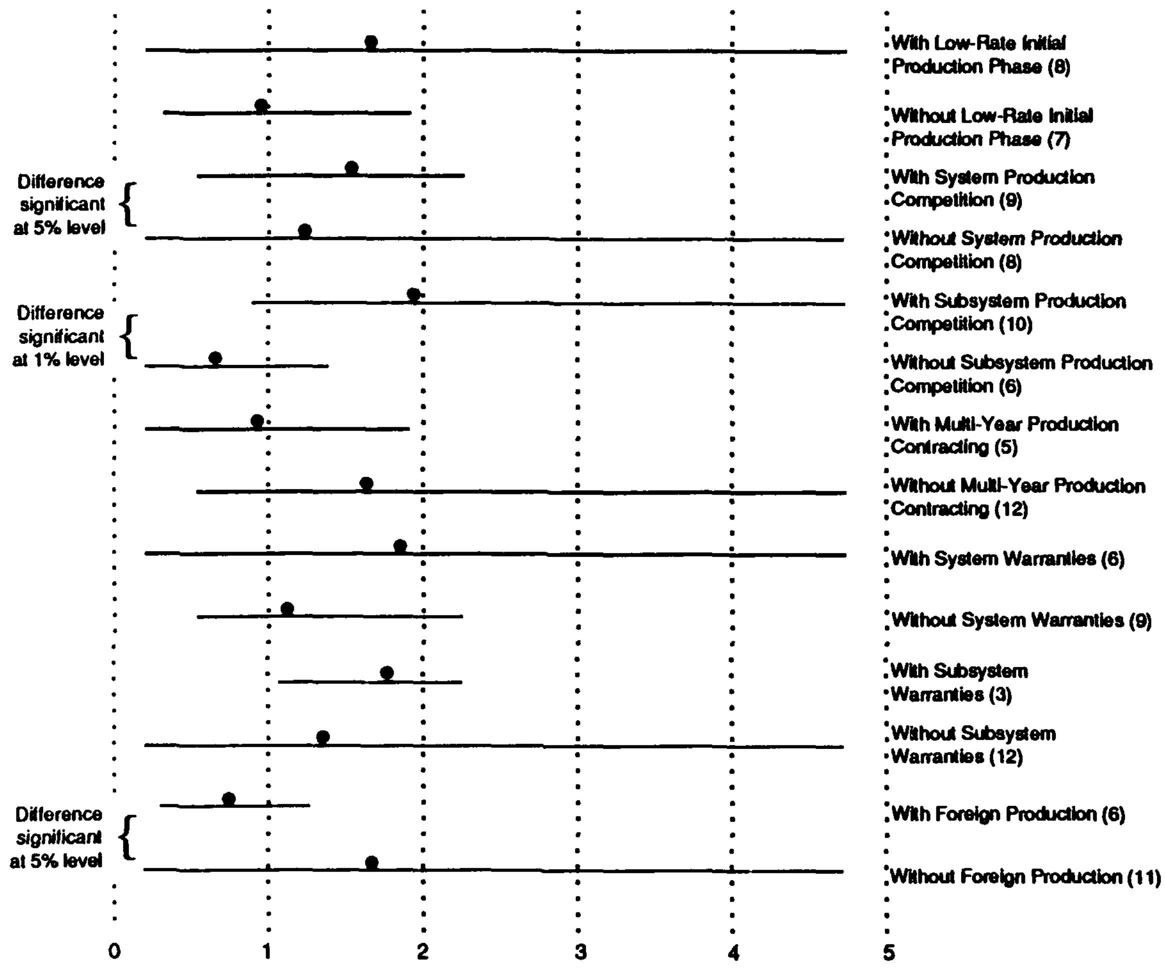
Production quantity growth was significantly related to the application of several acquisition policies during the production phase, as shown in Figure IV-22.[44] Average production quantity growth was higher for munitions with either system or subsystem production competition than for munitions with non-competitive production. Average production quantity growth was lower for munitions with foreign production than for munitions without foreign production. Foreign production may have taken the place of domestic production for foreign military sales.

The extent to which production quantity growth was related to the risks described in Chapter III is shown in Figure IV-23.[45] Production quantity growth was not related to the required levels of technological advance for performance, materials, or production processes, nor was it related to the percentage requirements for new test equipment, facilities, or tooling.[46] Production quantity growth was not significantly related to either of the procurement funding stability measures discussed in the previous chapter.[47]

G. PRODUCTION STRETCHOUT

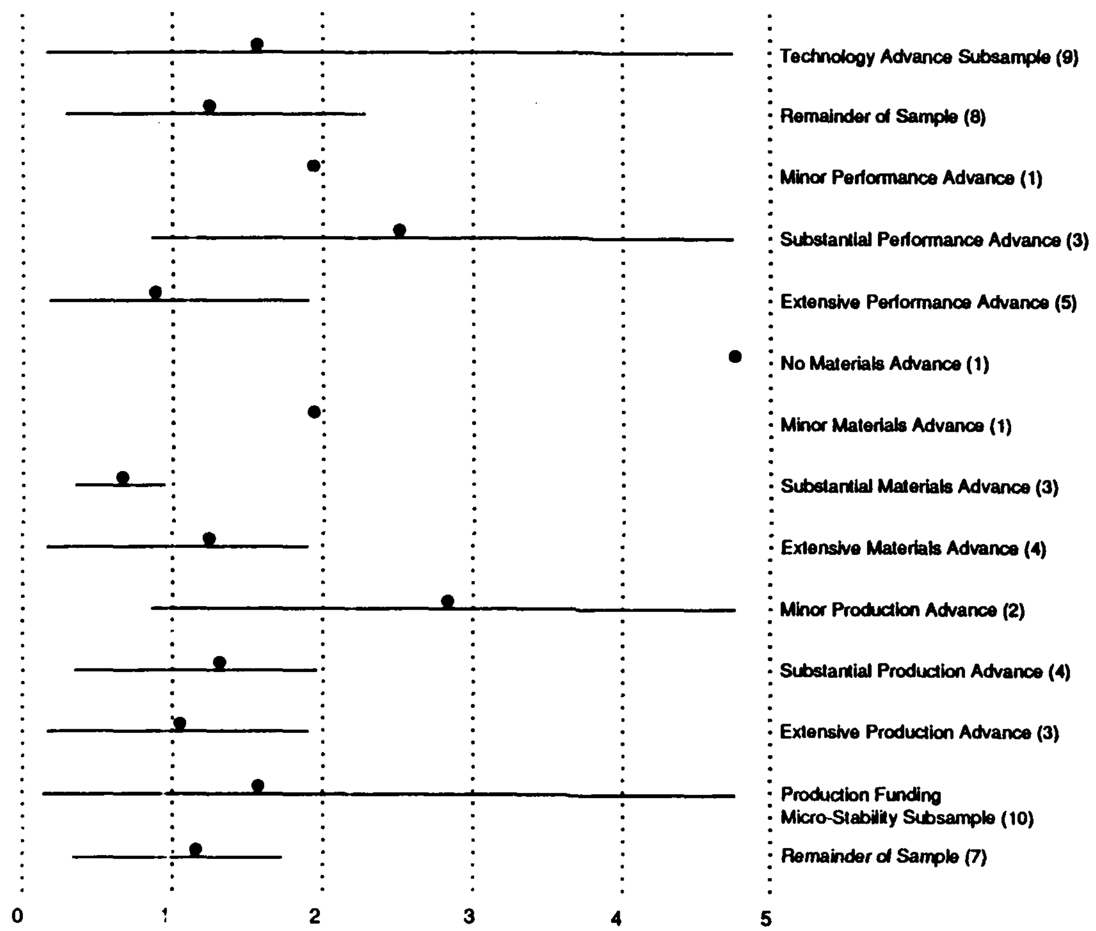
The development estimates and current estimates of (or actual) production end dates and production spans, and the production stretchout factors are shown in Table IV-10. The 5" Deadeye SALGP is excluded because the program was cancelled before it entered development.

The current estimates of production end dates for many of the munitions extend far beyond the development estimates. This happened for three separate reasons. The first is that production was started later than originally planned because of slippage in the



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-22. Range of Production Quantity Growth Factors for Applications of Each Acquisition Policy



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-23. Range of Production Quantity Growth Factors for Each Category of Program Risk

Table IV-10. Production End Dates, Production Spans, and Production Stretchouts

Designator	Title	New/ Mod	Originally Planned Production End Date	Development Estimate of Production Span (Months)	Current Estimate of Production End Date	Current Estimate of Prdocution Span (Months)	Production Stretchout Factor
A/RIM-7E	Sparrow III B CW	Mod	9/65	44	6/73	137	9.15
AIM-7F	Sparrow III Pulse Doppler	Mod	9/73	68	9/81	83	0.74
A/RIM-7M	Sparrow III Monopulse	Mod	9/85	51	9/89	82	1.17
AIM-9L	Sidewinder	Mod	9/77	41	9/85	113	2.25
AIM-9M	Sidewinder	Mod	9/85	57	9/92	139	1.07
AIM-54A	Phoenix	New	9/79	108	9/79	106	1.00
AIM-54C	Phoenix	Mod	9/86	86	9/81	141	0.34
AIM-120A	AMRAAM	New	9/94	128	9/98	I.U.	I.U.
FIM-92A	Stinger-Basic	New	I.U.	I.U.	I.U.	I.U.	2.86
FIM-92A	Stinger POST/RMP	Mod	9/90	72	9/94	120	0.88
AGM-65D/F/G	I/R Maverick	Mod	9/86	87	9/97	186	1.10
A/R/UGM-84A/C/D	Harpoon	New	9/81	75	7/94	229	2.21
AGM-88A	HARM	New	9/87	95	11/92	131	1.31
AGM-114A/B	Hellfire	New	9/86	58	9/93	138	1.20
BGM-71A	TOW It	New	9/72	73	9/82	166	3.85
BGM-71D	TOW II	Mod	9/96	108	3/92	126	1.31
–	MLRS-M77	New	9/88	100	9/92	148	1.19
M-712	Copperhead CLGP	New	9/86	103	9/88	106	5.56
Low				41		82	0.34
High				128		229	9.15
Mean				80		134	2.19

I.U. - Information unavailable.

development schedule, as discussed in the second section of this chapter. The second reason for extended production end dates is that production quantities increased beyond what was originally planned, as discussed in the previous section of this chapter. This increase would result in an increase in the production span if production rates were not changed. Production spans did increase for all but one of the munitions in the sample, as shown in Table IV-10.

The final reason for extended production end dates, and a reason for growth in the production spans over what was originally planned, is that production rates were reduced over the originally planned rates, resulting in production stretchouts. The production stretchout factor was calculated as the production span growth factor divided by the production quantity growth factor.[48] A production stretchout factor was not calculated for the AMRAAM because of uncertainty about the currently planned production quantity.

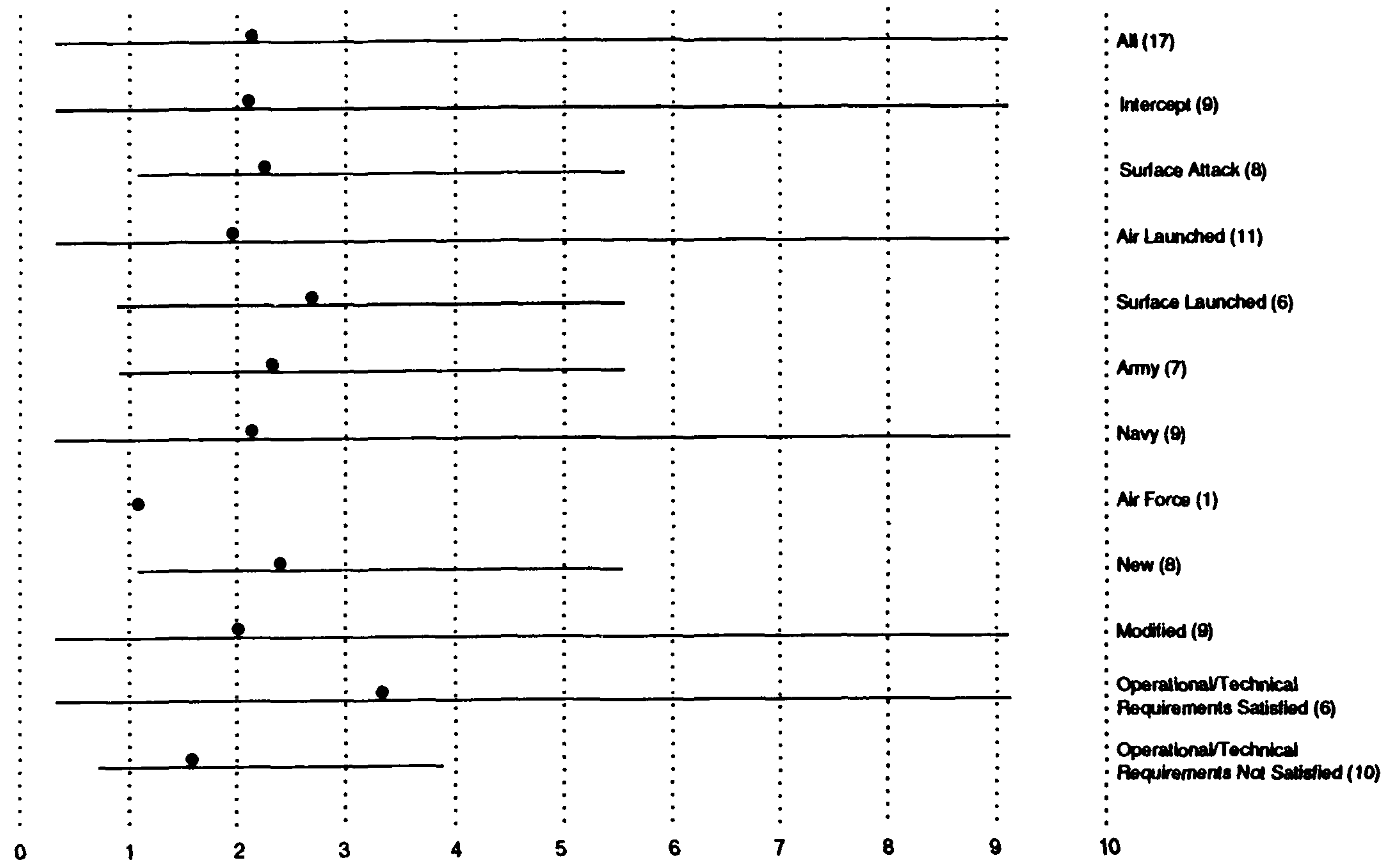
The range of production stretchout factors for each category of munition is shown in Figure IV-24.[49] Production stretchout did not vary significantly between any of the categories. Nor did production stretchout vary significantly between munitions whose operational and technical requirements were satisfied and munitions for which those requirements were not totally satisfied.

Production stretchout was inversely related to production quantity growth: the lower the production quantity growth, the higher the production stretchout.[50] Production stretchouts may have been used to retain active production capacity when either increases in production quantities or continuation of existing production rates could not be justified.

There was a positive correlation between production stretchout and production cost growth, but that correlation is not statistically significant.[51]

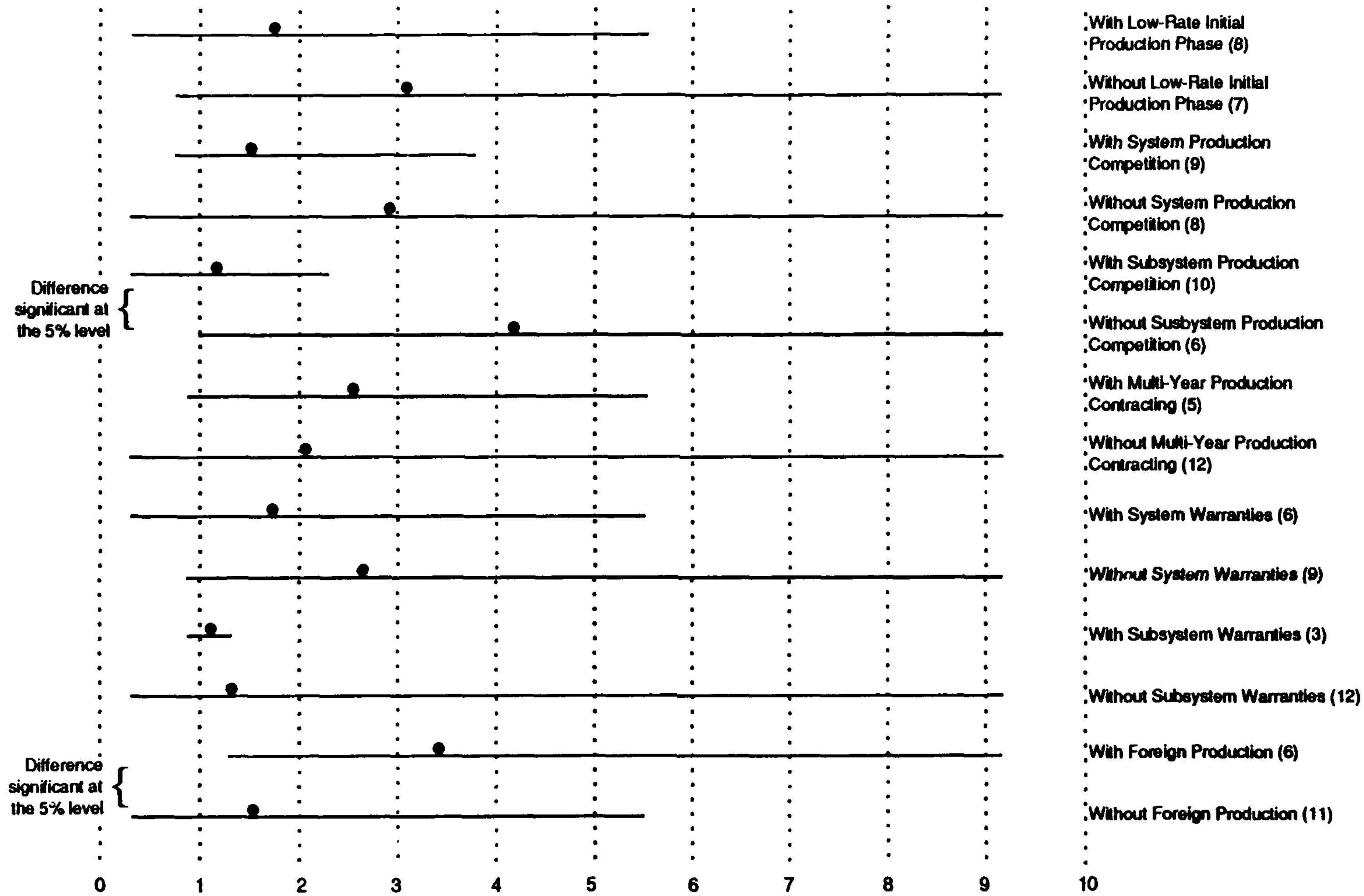
Production stretchout was inversely correlated with when the munition entered production.[52] This inverse correlation and the significant positive correlation between production quantity growth and when the munition entered production are related to the very strong inverse correlation between production stretchout and production quantity growth. The defense buildup in the first half of the 1980s resulted in lower stretchouts as well as higher production quantity growth.

Production stretchout was significantly related to two acquisition policies applied during the production phase, as shown in Figure IV-25.[53] Why production stretchout tended to be lower for munitions with competitive subsystem production is unclear.



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-24. Range of Production Stretchout Factors for Each Category of Munition



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-25. Range of Production Stretchout Factors for Applications of Each Acquistion Policy

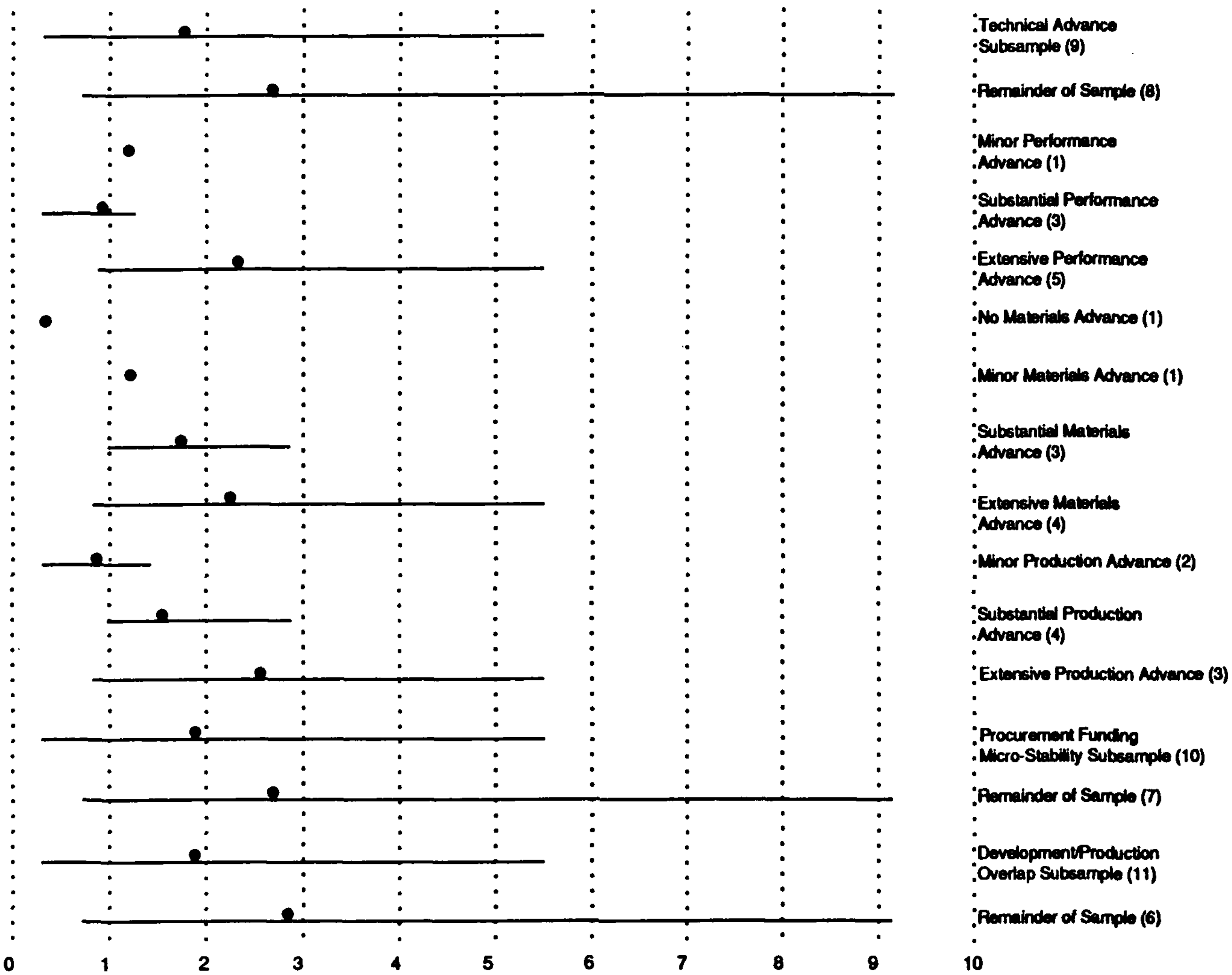
Production stretchout tended to be higher for munitions with foreign production than for missiles without, and the difference is statistically significant. As shown on Figure IV-22 in the previous section, production quantity growth tended to be lower for munitions with foreign production. The greater production stretchouts for munitions with foreign production is a reflection of the strong inverse relationship between production quantity growth and production stretchout.

The extent to which production stretchout was related to the risks described in Chapter III is shown in Figure IV-26.[54] Production stretchout was not related to the required levels of technological advance for performance, materials, or production processes, nor was it related to the percentage requirements for new test equipment, facilities, or tooling.[55] Production stretchout was not related to either of the funding stability measures nor to the development/production overlap ratios discussed in the previous chapter.[56]

H. TOTAL PROGRAM COST GROWTH

The estimates of total program costs made at the start of development, the current estimates of total program costs, what the total program costs would be if the development estimate quantities were produced, and the total program cost growth factors are shown in Table IV-11.[57] The development estimates of total program costs are from the earliest available SARs for the munitions, subsequently escalated from then-year dollars to 1989 dollars. The current estimates are from the latest SARs, also escalated to 1989 dollars. The quantity-adjusted total program costs, based on the quantity-adjusted production costs shown in Section F of this chapter, allow comparison with the development estimates of total program costs for the same production quantities. The total program cost growth factor is the quantity-adjusted total program cost divided by the development estimate of total program cost. Quantity-adjusted total program costs could not be estimated for the A/RIM-7E and AIM-7F Sparrow, the AMRAAM, the Stinger-POST/RMP, the TOW I, or the MLRS because of insufficient data. Development estimate program costs only are shown for the 5" Deadeye SALGP because that procurement program was cancelled before production started.

Current estimate total program costs averaged $3.3 billion in 1989 dollars for the twelve munitions for which quantity-adjusted production costs could be calculated. Quantity-adjusted total program costs averaged $2.7 billion in 1989 dollars, about $0.6 billion less than the average of the current estimates. This difference is due to changes in



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

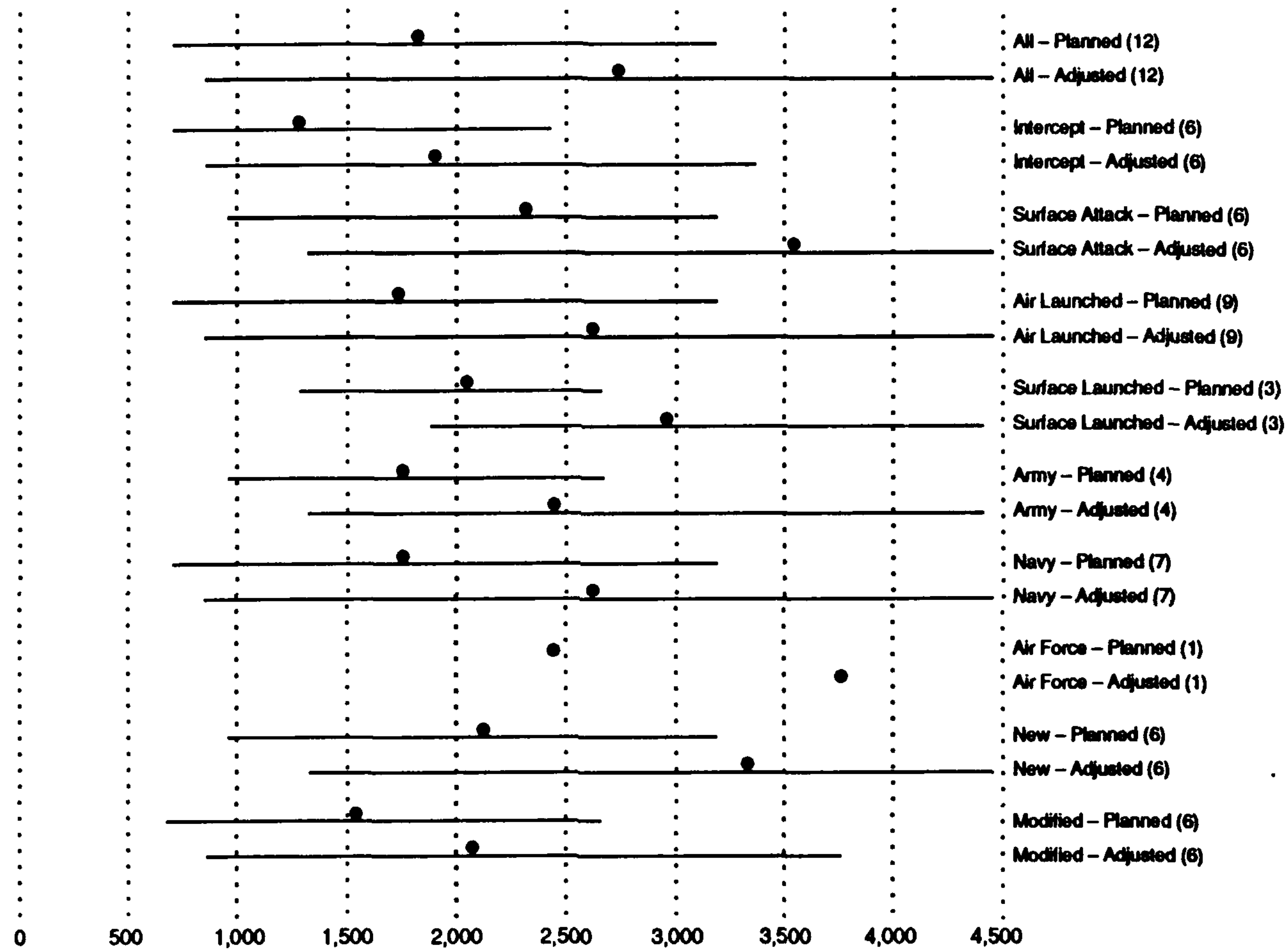
Figure IV-26. Range of Production Stretchout Factors for Each Category of Program Risk

the planned or actual production quantities since the programs were initiated. The ranges of development estimates and quantity-adjusted total program costs show large differences between categories of munitions, as shown in Figure IV-27.[58] The largest absolute and percentage differences are between intercept and surface attack munitions. The average total program costs for modifications are approximately two-thirds of those for the new munitions in the sample. This is because development costs, and production quantities and costs tended to be much less for the modifications in the sample.

Table IV-11. Total Program Costs and Total Program Cost Growth Factors

Designator	Title	New/ Mod	Development Estimate of Total Program Costs (89$ Millions)	Current Estimate of Total Program Costs (89$ Millions)	Quantity Adjusted Estimate of Total Program Costs (89$ Millions)	Total Program Cost Growth Factor
A/RIM-7E	Sparrow IIIB CW	Mod	4,996.6	2,188.9	I.D.	I.D.
AIM-7F	Sparrow III Pulse Doppler	Mod	1,582.4	4,002.1	I.D.	I.D.
A/RIM-7M	Sparrow III Monopulse	Mod	1,740.2	2,843.0	2,250.0	1.29
AIM-9L	Sidewinder	Mod	695.1	1,804.9	1,586.8	2.31
AIM-9M	Sidewinder	Mod	767.1	1,455.6	843.7	1.10
AIM-54A	Phoenix	New	2,408.9	3,276.7	3,320.2	1.38
AIM-54C	Phoenix	New	769.5	3,593.6	1,496.8	1.94
AIM-120A	AMRAAM	New	8,577.4	9,581.1	I.D.	I.D.
FIM-92A	Stinger-Basic	New	1,304.4	3,288.6	1,892.5	1.45
FIM-92A	Stinger POST/RMP	Mod	I.U.	I.U.	I.D.	I.D.
AGM-65D/F/G	IIR Maverick	Mod	2,462.6	6,776.2	3,768.4	1.52
A/R/UGM-84A/C/D	Harpoon	New	2,691.3	5,534.8	4,462.7	1.63
AGM-88A	HARM	New	3,184.1	4,592.1	4,435.2	1.39
AGM-114A/B	Hellfire	New	973.1	1,854.1	1,326.3	1.39
BGM-71A	TOW I	New	3,016.9	3,447.9	I.D.	I.D.
BGM-71D	TOW II	Mod	2,658.7	2,614.3	2,628.8	0.99
–	MLRS	New	4,236.7	4,811.0	I.D.	I.D.
M-712	Copperhead CLGP	New	2,088.8	1,743.6	4,447.2	2.12
–	5" Deadeye SALGP	New	720.2*	N.A.	N.A.	N.A.
Low			695.1	1,455.6	843.7	0.99
High			8,577.4	9,581.1	4,462.7	2.31
Mean-Overall			2,597.3	3,729.9	2,704.9	1.54
Mean-Cost Growth Sample			1,812.0	3,281.5	2,704.9	1.54

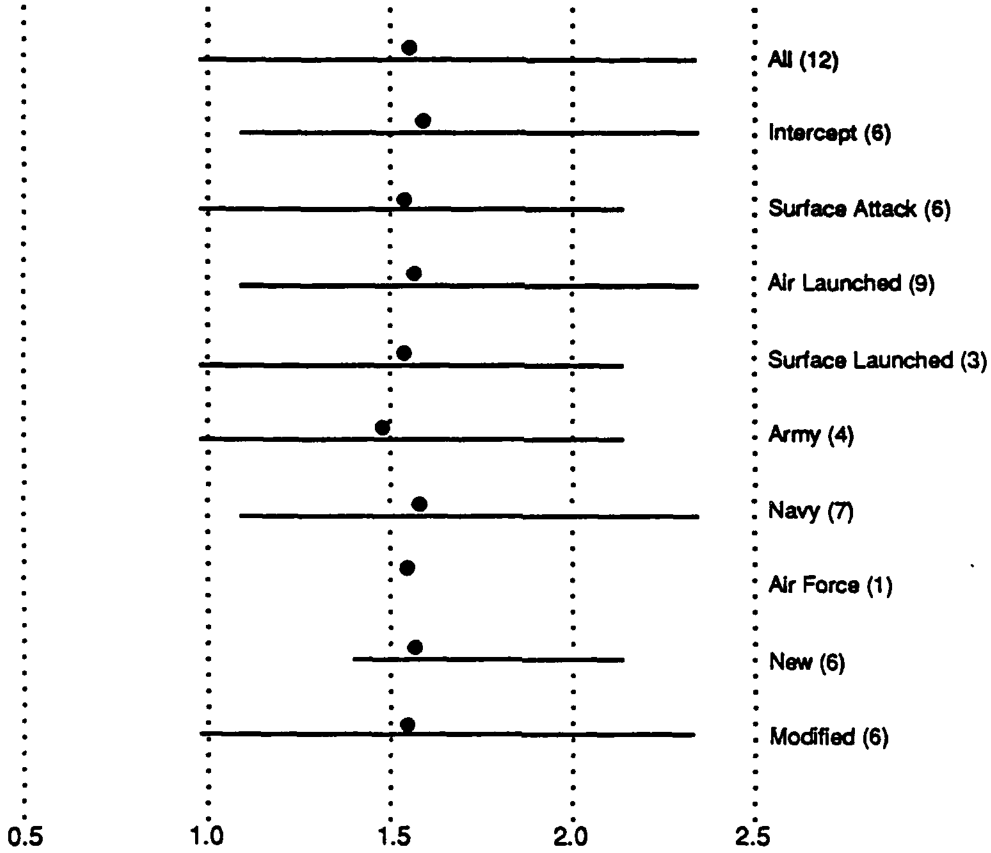
I.U. - Information unavailable.
I.D. - Insufficient data.
N.A. - Not applicable.
*Not included in averages



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-27. Range of Planned and Adjusted Estimates of Total Program Costs for Each Category of Munition

For each of the categories of munitions, the average quantity-adjusted total program cost was higher than the average development estimate total program cost. Total program costs increased by an average of 54 percent for the twelve munitions for which quantity-adjusted production costs could be calculated. As shown in Figure IV-28, there is a remarkable degree of uniformity for the total program cost growth factors between the categories of munitions, with no statistically significant differences between the categories.[59]



Notes: Numbers in parentheses are sample sizes. Bullets (●) indicate the means.

Figure IV-28. Range of Total Program Cost Growth Factors for Each Category of Munition

Total program cost growth was directly correlated with production cost growth, with a very high level of statistical significance.[59] Total program cost growth was not correlated with development cost growth, which is consistent with the absence of any correlation between production cost growth and development cost growth, as previously discussed.[60]

V. FINDINGS AND RECOMMENDATIONS

This chapter presents the lessons learned from the analyses in the preceding chapters and from the case studies in Volume II. Recurring pitfalls leading to problems are identified, and recommendations are made for avoiding them. To provide a context for this discussion, the chapter opens with a summary of the outcomes of the acquisition programs for the munitions in the sample.

A. SUMMARY OF ACQUISITION PROGRAM OUTCOMES

The acquisition program schedules, costs, and quantities are summarized in Table V-1 for the nineteen munitions in the sample. Advanced development averaged 41 months in duration and full scale development averaged 85 months. There was large variability about these averages, leaving considerable uncertainty about how long each of these phases of the development program should take. The average full scale development schedule for modified munitions was almost one year, 14 percent longer than for new munitions. Both the development quantity and development cost for modified munitions were approximately one-third of the corresponding numbers for new munitions. Development costs accounted for approximately 6 percent of the total program costs for modified munitions and approximately 15 percent for new munitions. The average total program cost for the modified munitions was approximately 75 percent of the average total program cost for the new munitions, but the average production quantity for the modified munitions was approximately 40 percent of that for new munitions. The result is that the average unit cost for the modified munitions ($93,782) was almost twice as high as for new munitions ($50,271). These numbers suggest that acquisition programs for modifications require comparable management procedures and the same degree of management attention as are required for the acquisition programs for new munitions.

These patterns are reinforced by the acquisition program outcome measures, which are summarized in Table V-2. Quantity-adjusted total program cost increased by an average of 54 percent over what was originally planned. Total program cost growth differed very

Table V-1. Summary of Acquisition Program Schedules, Costs, and Quantities

Designator	Name	Advanced Development (Months)	Full Scale Development (Months)	Development Quantity	Development Cost (89$ Millions)	Production Cost (89$ Millions)	Currently Planned Production Quantity	Currently Planned Production Span (Months)	Total Program Cost (89$ Millions)
A/RIM-7E	Sparrow IIIB CW		47	44	62.1	2,126.8	19,661	137	2,188.9
AIM-7F	Sparrow III Pulse Doppler		124	134	356.3	3,645.8	16,145	83	4,002.1
A/RIM-7M	Sparrow III Monopulse	38	57	44	94.0	2,749.0*	15,274*	82*	2,843.0*
AIM-9L	Sidewinder		81	123	195.4	1,609.5	11,350	113	1,804.9
AIM-9M	Sidewinder		79	134	134.2	1,321.4*	16,937*	139*	1,455.6*
AIM-54A	Phoenix	75	56	37	552.1	2,724.6	2,285	106	3,276.7
AIM-54C	Phoenix		122	45	234.9	3,358.7*	3,356*	141*	3,593.6*
AIM-120A	AMRAAM	46	94*	111*	1,299.9*	8,281.2*	24,320*	I.U.*	9,581.1*
FIM-92A	Stinger-Basic	I.U.	105	179	317.2	2,971.4*	8,085	I.U.	3,288.6*
FIM-52A	Stinger POST/RMP		134*	29*	182.2*		42,555*	120*	
AGM-65D/F/G	IIR Maverick	I.U.	113	33	236.7	6,539.5*	60,664*	186*	6,776.2*
A/R/UGM-84A/C/D	Harpoon	33	50	52	895.8	4,639.0*	3,971*	229*	5,534.8*
AGM-88A	HARM	45	69	99	569.2	4,022.9*	14,438*	131*	4,592.1*
AGM-114A/B	Hellfire	45	125	229	506.8	1,347.3*	48,696*	138*	1,854.1*
BGM-71A	TOW I	17	89	472	422.5	3,025.4*	137,275*	166*	3,447.9*
BGM-71D	TOW II		61	113	179.6	2,434.7*	125,856*	126*	2,614.3*
–	MLRS	32	70	470	466.0	4,345.0*	452,322*	148*	4,811.0*
M-712	Copperhead CLGP	40	90	320	296.4	1,447.2*	24,546*	106*	1,743.6*
–	5" Deadeye SALGP	I.U.	49	141	209.7	N.A.	N.A.	N.A.	N.A.
Low		17	47	29	62.1	1,321.4	2,285	82	1,455.6
High		75	134	472	1,299.9	8,281.2	452,000	229	9,581.1
Mean-New		42	80	211	553.6	3,644.9	79,549	146	4,236.7
Mean-Modification		38	91	78	186.2	2,973.2	34,644	125	3,159.8
Mean-Overall		41	85	148	379.5	3,328.8	57,096	134	3,729.9

I.U. - Information unavailable.
N.A. - Not applicable.
* - SAR estimate.

Table V-2. Summary of Acquisition Program Outcomes

Designator	Name	New/ Mod	Operational and Technical Requirements Satisfied	Development Schedule Growth Factor	Development Quantity Growth Factor	Development Cost Growth Factor	Quantity-Adjusted Production Cost Growth Factor	Production Quantity Growth Factor	Production Stretchout Factor	Quantity-Adjusted Total Program Cost Growth Factor
A/RIM-7E	Sparrow IIIB CW	Mod	Yes	1.00	1.00	0.84	I.D.	0.34	9.15	I.D.
AIM-7F	Sparrow III Pulse Doppler	Mod	No	2.82	3.94	4.27	I.D.	1.66	0.74	I.D.
A/RIM-7M	Sparrow III Monopulse	Mod	No	1.46	1.00	0.98	1.31	1.38	1.17	1.29
AIM-9L	Sidewinder	Mod	No	2.45	4.10	4.89	2.12	1.23	2.25	2.31
AIM-9M	Sidewinder	Mod	No	1.01	1.94	2.04	1.01	2.27	1.07	1.10
AIM-54A	Phoenix	New	No	1.19	0.82	1.54	1.35	0.98	1.00	1.38
AIM-54C	Phoenix	Mod	Yes	1.45	1.50	1.67	2.01	4.76	0.34	1.94
AIM-120A	AMRAAM	New	Unknown	1.74	0.66	1.40	I.D.	I.D.	I.D.	I.D.
FIM-92A	Stinger-Basic	New	Yes	1.64	0.81	1.46	1.45	0.35	2.86	1.45
FIM-92A	Stinger-POST/RMP	Mod	Unknown	1.06	1.00	2.34	I.D.	1.90	0.88	I.D.
AGM-65D/F/G	IIR Maverick	Mod	Yes	1.98	0.94	1.07	1.58	1.95	1.10	1.52
A/R/UGM-84A/C/D	Harpoon	New	No	1.35	1.00	1.06	1.93	1.38	2.21	1.63
AGM-88A	HARM	New	No	1.21	1.00	1.42	1.39	1.05	1.31	1.39
AGM-114A/B	Hellfire	New	No	1.44	0.95	1.09	1.61	1.98	1.20	1.39
BGM-71A	TOW I	New	No	1.51	1.01	1.20	I.D.	0.59	3.85	I.D.
BGM-71D	TOW II	Mod	Yes	1.02	1.00	1.70	0.96	0.89	1.31	0.99
–	MLRS	New	No	1.00	0.72	1.03	I.D.	1.25	1.19	I.D.
M-712	Copperhead CLGP	New	Yes	1.73	0.78	1.28	2.23	0.19	5.56	2.12
–	5" Deadeye SALGP	New	Yes	1.00	0.65	1.16	N.A.	N.A.	N.A.	N.A.
Low				1.00	0.65	0.84	0.96	0.19	0.34	0.99
High				2.82	4.10	4.89	2.23	4.76	9.15	2.31
Mean-New			0.30	1.38	0.84	1.26	1.66	0.97	2.40	1.56
Mean- Modified			0.44	1.58	1.83	2.20	1.50	1.82	2.00	1.53
Mean-Overall			0.41	1.48	1.31	1.71	1.58	1.42	2.19	1.54

N.A = Not applicable.
I.D. = Insufficient data.

little between any of the categories of munitions. The relationships between program outcomes and the effects of the various risks and acquisition policies applicable to each munition are discernable only when program outcomes are disaggregated into more detailed measures and data are obtained from detailed studies of individual munitions.

Development schedules slipped by an average of 48 percent over what was planned, and no statistically significant differences were seen between categories of munitions. Development schedule growth was not directly related to any of the measures of risk, or to any of the acquisition policy initiatives. Development schedule growth was affected by problems that subsequently affected production costs.

Development quantity growth and development cost growth were directly related for the munitions in the sample, but neither measure was related to development schedule growth. Development cost growth was significantly greater for intercept missiles than for surface attack missiles, while development quantity growth was significantly greater for air-launched than for surface-launched munitions, and for modified munitions than for new munitions. The case studies in Volume II indicate that the original estimates of development quantities and costs (and difficulties) were overly optimistic. Both development quantity growth and development cost growth were significantly lower for munitions that had advanced development phases and advanced development prototypes. Development quantity growth was also significantly lower for munitions that had independent cost analysis. Development cost growth was significantly lower for munitions that had competition at the subsystem level during full scale development. Development cost growth was inversely related to the percentage requirements for new facilities; munitions with higher development cost growth tended to have lower percentages of floor area in new facilities.

Production costs for the development estimate quantities increased by an average of 58 percent over what was originally planned. Production cost growth was not significantly different between any of the categories of munitions. Production cost growth was not related to either development cost growth or development quantity growth, but was directly related to development schedule growth. Producibility problems that resulted in increased production costs appear to have surfaced during development, causing slippage in the development schedule. Production cost growth was directly correlated to both procurement budget growth ("procurement funding macro-stability"), and the extent of overlap between full scale development and production. Production cost growth did not differ significantly with any of the other measures of program risk, or with the applicability

of any of the acquisition program initiatives. Specifically, production cost growth was not affected by multi-year contracting, or by competition at either the system or subsystem levels of production.

Production quantities increased by an average of 42 percent over what were originally planned. Again, there was large variability about the average. Little or no credence should be given early estimates of planned production quantities. Production quantity growth did not differ significantly between any of the munition categories. Even though average production quantity growth for new and modified munitions differed by approximately a factor of two, the difference is not statistically significant because of the extreme variability about the two averages. Production quantity growth was not related to production cost growth. Production quantity growth was significantly greater for munitions with system or subsystem competition, and for munitions without foreign production. As noted in several of the case studies in Volume II, production competition becomes more feasible with larger production quantities. Foreign production reduced the domestic production below what it might otherwise have been.

Production of the originally planned quantities stretched out an average of 119 percent over the original schedule. Production stretchout was not significantly different between any of the munition categories. Production stretchout had a significant inverse relationship with production quantity growth, but a statistically significant direct relationship with production cost growth could not be established. As might be expected because of the strongly significant inverse relationship with production quantity growth, production stretchout was less for munitions with subsystem production competition and for munitions without foreign production. Without foreign production, there is an incentive to stretch production to maintain a production base for domestic and foreign sales.

All operational and technical requirements listed in the SARs were satisfied for 41 percent of the seventeen munitions that have competed development testing. That 59 percent were deployed without fully satisfying their operational and technical requirements suggests that the requirements might have been unduly stringent. This is further supported by no statistically significant differences in production quantity growth between the munitions that satisfied those requirements and the munitions that did not. None of the other program outcome measures differed significantly between whether or not the operational and technical requirements were satisfied. The percentage of munitions satisfying the operational and technical requirements did not vary significantly among any of the acquisition policies applied. The percentage was lower for munitions with extensive

requirements for advances in performance and production technologies. Percentage requirements for new test equipment were significantly lower for munitions that satisfied all operational and technical requirements.

The two munitions that faced substantial changes in the threat during development (IIR Maverick and HARM) differed from the remainder of the munitions in the sample in that both had advanced development phases with either system or subsystem prototypes, independent cost estimates, independent testing, and system warranties. None of the outcome measures for these two munitions varied significantly from the outcome measures for the remainder of the munitions in the sample. If this risk had any effect on development quantity growth or development cost growth, it may have been offset by the effects of the acquisition policies that were applied. For all of the munitions in the sample, development quantity growth and development cost growth were lower for munitions which had advanced development, prototypes, and independent cost estimates. However, there is no way to test whether or not any effects of these policies on development quantity growth or development cost growth may have been offset by threat changes, because there were no munitions with threat changes but without application of these policies.

Of the outcome measures shown in Table V-2, only two have shown any statistically significant improvement over time. Development quantity growth and production stretchout have both decreased. None of the measures has gotten worse. Production quantity growth has been higher for the munitions that entered production later. To some extent that is an artificiality, because for a number of the older munitions in the sample, production quantities increased and then were reduced when future planned production quantities were transferred to follow-on modifications.

Several other factors have affected the outcome measures. The first has to do with the sample itself. The sample includes several new, Army-managed, surface attack, surface- launched munitions with very large production quantities. Planned development schedules, development quantities, and development cost estimates for these munitions tended to be conservative, showing less than average subsequent growth. In contrast, several Navy-managed modifications of air-launched intercept missiles in the sample had planned development schedules, development quantities, and development cost estimates that tended to be overly optimistic.

The second factor affecting the outcome measures was the defense buildup of the 1980s. Production quantity growth was higher and production concurrency and

production stretch were lower for the munitions that entered production during the first half of the 1980s when defense procurement budgets increased. Since production cost growth did not show any trend with time, the effect of the lower concurrency ratios during that period was to limit production cost growth to less than it would have been otherwise.

A third factor affecting the outcome measures was the interrelated effects of technological risk, requirements for new resources, and the application of several of the acquisition policies. Munitions with higher technology and new resource requirements also tended to have advanced development phases and independent cost estimates. Munitions which had higher technology and new resource requirements and which also had advanced development phases and independent cost estimates had significantly lower development quantity growth factors and development cost growth factors than did munitions which had low technology and resource requirements and which did not have advanced development phases and independent cost estimates. For the entire sample, development quantity growth was significantly lower for munitions with advanced development phases and independent cost estimates; development cost growth was significantly lower for munitions with advanced development phases. Both development quantity growth and development cost growth were higher for the one munition which had high technology requirements, but did not have an advanced development phase or an independent cost estimate, than for any of the other munitions with high technology requirements which did have advanced development phases and independent cost estimates. This would suggest that the effects of the technology risks may have been offset by advanced development and independent cost estimates, but the sample size is not large enough to test for statistically significant differences.

There were no munitions which had high resource requirements, but which did not have advanced development phases or independent cost estimates. Nor were there any munitions in the technology and resource requirements subsample which had advanced development phases and independent cost estimates, but which also had low requirements for new resources. As a result, the effects on development quantity growth and development cost growth of the resource requirements risks could not be separated from the effects of advanced development and independent cost estimates.

For a similar reason, it is not possible to separate out the effects on production cost growth of high technology and new resource requirements from the effects of low rate initial production. There were not enough munitions in the technology and resource requirements subsample with either low requirements for new technology or resources, or

which did not have low rate initial production phases, to test for statistically significant differences.

By similar reasoning, the outcomes were affected by the interactions between whether the munitions were new or modified and whether or not they underwent advanced development. All of the new munitions underwent advanced development, while only two of the modified munitions did. Both development quantity growth and development cost growth were significantly lower for munitions that underwent advanced development. There was no way to test the effects of advanced development on the program outcome measures for new munitions. For the modified munitions in the sample, development quantity growth and development cost growth averages were lower by half for the modified munitions that underwent advanced development than for those that did not, but because of the small sample size, it was not possible to show that these differences were statistically significant.

The effect of competition on the program outcome measures was limited. Competition in the advanced development phase had no discernible effect on development schedule, quantity, or cost growth. None of the munitions in the sample had competition at the system level during full scale development. Development cost growth was significantly lower for munitions with competition at the subsystem level during full scale development, but neither development schedule nor development quantity growth were affected. Production quantity growth was greater for munitions with production competition, but as noted above, the direction of causation is not clear.

Finally, two other acquisition policies -- independent testing and multi-year contracting -- had no discernable effects on any of the outcome measures. The lack of statistically significant differences in (1) any program outcomes for these two policies, and (2) in some program outcomes for other policies, may be due to the small sample size. A larger, better stratified sample might uncover more statistically significant relationships.

B. PITFALLS: MAJOR PROBLEMS AND WHY THEY RECUR

Several recurring problems were observed from the analyses in the preceding chapters and from the case study examples of Volume II that affected the outcomes of the acquisition programs for the munitions in the sample.

1. Recurring Pitfall No. 1

The time and funds necessary for development of modifications were consistently underestimated. Development testing requirements were optimistic in terms of both the numbers of test articles required and the test schedule. For the AIM-7F Sparrow modification, 4 months were planned for technical evaluation, but 22 months were actually required; 3 months were planned for operational evaluation, but 30 months were actually required. Technological difficulties were seriously underestimated for the AIM-9L Sidewinder modification -- 33 months for development, 30 test articles, and a high degree of concurrency between development and production were originally planned. Subsequently, the development program was drastically revised. The technological requirements for the change from analog to digital components in the guidance and control section modification of the AIM-54C Phoenix were also underestimated. The amount of time required to develop the imaging infra-red seeker for the IIR Maverick was grossly underestimated, as were the development costs for the TOW II.

The result was development schedule growth and development cost growth for modifications being as high as for new weapons, and development quantity growth for modifications being much higher than for new weapons. This is primarily because most of the modifications involved large changes to the sensors, software, avionics, and other electronics subsystems, which comprise over 60 percent of the cost of most munitions.

2. Recurring Pitfall No. 2

Technological uncertainties were not adequately identified early in the development programs. Technology availability was consistently overestimated. This was reflected in large growth in development schedules and quantities and in development and production costs. Technological difficulties associated with the development of the pulse-Doppler seeker and guidance system for the AIM-7F Sparrow, and the all-aspect seeker for the AIM-9L Sidewinder did not surface until well into the development program. The technological requirements for a long-range launch-and-forget missile for fleet air defense were originally underestimated in the AIM-54A Phoenix program, as were the subsequent requirements for the solid-state modification of the AIM-54C. The technological requirements of the AMRAAM were originally assessed in comparison to the AIM-7 Sparrow, but were much more similar to what the requirements would be for a miniaturized Phoenix. The Air Force's all-weather, day and night operational requirement for the IIR Maverick exceeded what could be done with the technology available at the start of full

scale development. The technological requirements of the 5" Deadeye SALGP were originally assessed in comparison to the Copperhead without adequate consideration of the extensive miniaturization (to 17 percent of the volume in Copperhead) that would be required for the guidance and control electronics. In contrast, the technological requirements were well- identified, and the technology was available at the start of development for both the Hellfire's semi-active laser seeker and for the MLRS.

A risk management system is needed during program execution to track and obtain feedback on technical trends, as well as schedule and cost trends. Important technological ingredients in the program need to be quantified with respect to the trends in technology over time in order to understand how far the state-of-the-art is being pushed. Technical trends over time are not well-understood outside of missile propulsion systems and aircraft engines and airframes. Similar analyses need to be done for software, guidance and control subsystems, warheads, and production processes. The availability of such information would be of great value in determining the requirements for advanced development prototypes and exploratory development testing.

3. Recurring Pitfall No. 3

Design and production concepts were inadequately demonstrated and evaluated in several of the development programs. Advanced development prototyping was not always successful in eliminating the major technological uncertainties for the munitions in the sample. Prototyping was generally restricted to the munition itself, but even in this restricted sense, it was not always totally successful in eliminating technological uncertainties. For example, the technology embodied in advanced development prototypes for the AMRAAM differed substantially from what finally evolved during full scale development: the solid-state transmitter in the prototype was not capable of satisfying the operational and technical requirements of the missile and had to be replaced with a transmitter based on traveling-wave-tube technology, which required extensive development efforts for miniaturization and cooling. For that missile, the competitive advanced development prototypes served more as a basis for contractor selection than as a means for reducing technological uncertainty. The original plan for testing 10 missiles from each contractor was reduced to 5 missiles from Raytheon and 3 from Hughes. The testing of the advanced development prototypes did not adequately demonstrate that the technology was in hand. In contrast, the competitive advanced development of the MLRS produced prototypes that achieved good results during testing, thereby demonstrating that

the technology was in hand. The competitive advanced development of the Hellfire had similar beneficial effects on limiting development cost growth.

Prototyping of production processes was not generally done for the munitions in the sample, either in advanced development or in full scale development. The result was lower-than-expected yield levels from new production processes, resulting in high production cost growth for the HARM and the Copperhead. Uncertainties as to production process feasibility and cost, as well as uncertainties as to the munition's technical and performance feasibility and cost, need to be addressed and reduced during advanced development.

4. Recurring Pitfall No. 4

Producibility was not adequately considered in the design decisions for several of the munitions in the sample. This resulted in producibility and quality-control problems, which caused production costs to increase. Producibility and quality-control problems with the AIM-54C resulted in high production cost growth and the Navy's non-acceptance of deliveries in June 1984. Fabrication and quality-control problems resulted in half of the first 20 AMRAAM development test missiles being returned to the contractor because of defects. Completion of a compressed development schedule for the Harpoon, in order to counter an immediate threat, was emphasized to the detriment of producibility, resulting in higher than average production cost growth. Producibility problems with the circuit boards and seeker for the HARM required much more extensive testing with expensive labor than was anticipated. Production planning for the Copperhead was initiated approximately two years after the start of full scale development, too late to make any substantial design changes to enhance producibility, resulting in the highest production cost growth of any of the munitions in the sample. More emphasis needs to be placed on understanding early in development the cost of producing the article in quantity.

5. Recurring Pitfall No. 5

Unrealistic test planning contributed to development schedule growth, development cost growth, and product unreliability for several of the munitions in the sample. For modified munitions, estimates of the numbers of test articles that would be required were woefully inadequate. For the intercept and anti-radar munitions, estimates of the time that would be required for each firing were generally overly optimistic because of inadequate consideration or knowledge of competing requirements by other development programs for

limited test resources. The AIM-54A Phoenix development schedule was delayed by limited availability of F-111B test aircraft and delays in the F-14A flight test program. Testing of the AMRAAM has been extensively delayed by problems with weather, targets, and launch aircraft, and by funding limitations for a third test site. An optimistic test schedule for the HARM was subsequently constrained to fewer than the planned number of firings because of limitations in the availability of test facilities, particularly for testing of software.

Slippage in the test schedule for the AIM-54A Phoenix led to a reduction in the development quantity in order to save on development costs and limit the slippage in the development schedule. Development quantities were also reduced below originally planned levels in order to save on the development costs for the IIR Maverick and the Copperhead. The result was that reliability problems were not discovered until initial production.

6. Recurring Pitfall No. 6

Procurement plans with larger overlaps between development and production were generally overtaken by unforeseen problems, and had to be restructured for several of the munitions in the sample. Inadequate recognition was given to the possibility of technological problems during testing and early operational use. As shown in Chapter IV, the extent of development/production overlap was directly correlated with production cost growth for the munitions in the sample. Extensive overlaps between development and production in the acquisition programs for the AIM-9L Sidewinder, AIM-54C Phoenix, Harpoon, and Copperhead were accompanied by big growths in production costs. Because of early failures in testing, the AIM-9L Sidewinder acquisition program subsequently had to be restructured to allow technical problems to be identified and corrected before production. Reliability problems with the AIM-54C Phoenix and the Copperhead subsequently resulted in delayed deliveries of production munitions. The simultaneous time frame for development test and evaluation and initial operational test and evaluation has contributed to the high development cost growth and extensive development schedule slippage in the AMRAAM acquisition program. Low reliability during testing resulted in stretchout of TOW I production.

7. Recurring Pitfall No. 7

Available methods for estimating schedules and costs were inadequate for most of the munitions in the sample. Estimates of the time and resources required to meet

technological objectives during development programs were not consistent with trends over time in the technological state-of-the-art. Actual times required for development of analogous subsystems were neither consistently considered nor incorporated into the schedule estimates. The tradeoffs between development task accomplishment times and the amounts of development resources applied were not well-understood for the different categories of munitions subsystems.

Production costs for the early part of the production phase often showed Unit 1 costs increasing by a factor of 3-10 with a steeper learning curve for many of the munitions in the sample; Unit 1 and slope were consistently misestimated. Original production schedule and cost estimates were very optimistic, and did not always incorporate the production experience of analogous subsystems. Where there was no comparable experience in production, there was a potential for large cost growth production if schedule and cost uncertainties had not been adequately addressed during development. More emphasis needs to be placed on understanding early in development the cost of producing the article in quantity.

8. Recurring Pitfall No. 8

Independent review of risks, schedules, costs, and test requirements and results was not consistently applied. The military services and the contractors were almost perpetually optimistic about what could be accomplished. This predilection to program new systems for success will naturally bias the early cost and schedule estimates. Checks and balances are necessary between OSD and the military services. It does not hurt to have a "devil's advocate" on the staff to question the need for systems and the critical assumptions underlying the schedule and cost estimates.

C. RECOMMENDATIONS

1. Major munition modification programs require the same types of management procedures and measures to identify and manage acquisition program risks as do new munition acquisition programs. Modification programs should be subjected to concept exploration and advanced development phases with Milestone 0 (Mission Needs Determination) and Milestone I (Concept Selection) reviews. Advanced development prototypes of appropriate subsystems and production processes should be required to adequately demonstrate achievement of performance and producibility requirements prior to entering into full scale development.

2. Technological risks, in terms of performance and production processes, need to be identified at the start of development. Technology trending models should be used for identifying potential risks in the development of software, guidance and control subsystems, warheads, and production processes. Such models have been successfully developed and used for identifying technological risks of developing aircraft airframe and propulsion subsystems and missile propulsion subsystems. Similar models need to be developed for software, guidance and control subsystems, warheads, and many types of production processes.

3. Technological risks, in terms of munition performance and production processes, need to be systematically reduced as early in development as possible. Advanced development prototyping of high-risk performance and production technologies should be required, and the results should be independently reviewed before the Milestone II program go-ahead decision. Competitive development should be evaluated as a means to obtain alternative solutions to technological problems.

4. Producibility should be demonstrated and independently reviewed before the Milestone IIIA production release decision. Initial production should be at a low rate until problems have been identified and corrected during early production and operational experience. Overlaps between development and production should be minimized to the extent possible.

5. Improve schedule and cost-estimating procedures and models by requiring systematic identification and incorporation of uncertainties and time and cost tradeoffs and use of appropriate data bases and analogies. Separate estimates should be made for important subsystems. Where resources such as test ranges and test vehicles (and crews) are shared between acquisition programs, require that the resource constraints and other demands on those resources be adequately reflected in schedule and cost estimates.

6. Emphasize the assessment of risks, schedules, costs, and test results at the OSD level, independent of the military service. Require consistent, full reporting in the SARs or Defense Acquisition Executive Summaries (DAES) to identify the program risks, describe the acquisition strategy, show important subsystems separately, provide a summary of test results, provide complete non-recurring/recurring cost splits and scope changes, and include joint service and foreign military sales costs and quantities.

Checklists of critical questions should be used at Defense Acquisition Board reviews. A draft of such a checklist is included as Appendix B.

7. Conduct an on-going systematic effort at the OSD staff level to measure acquisition program effectiveness. Alternative acquisition policies should be compared, in a manner similar to what has been done in this report, except across a wider sample of acquisition programs, to determine which policies have been effective. Acquisition program histories should be documented in case studies similar to those in Volume II of this report, to provide a corporate memory of lessons learned.

NOTES

II-1. The statistical significance of the relationships between whether or not there was an advanced development phase, competition at the subsystem level during full scale development, independent testing, or independent cost estimates was calculated from Fisher's exact probability test for a 2x2 contingency table with small sample sizes:

FSD Subsystem Competition for	Probability
4 of 12 with AD and 0 of 7 without AD	12.8%

Independent Testing for	Probability
3 of 12 with AD and 0 of 7 without AD	22.7%

Independent Cost Estimates for	Probability
6 of 12 with AD and 0 of 7 without AD	3.4%

II-2. A test using the Table of the Total Number-of-Runs Test for Randomness in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal sample sizes was performed to test whether or not subsystem production competition is randomly distributed over time. There are four runs in the data. The probability of four or fewer runs with samples of ten competitive munitions and seven non-competitive munitions is equal to .024.

II-3. The statistical significance of the relationships between whether or not there was system production competition and/or subsystem production competition was calculated from Fisher's exact probability test for a 2x2 contingency table with small sample sizes:

Subsystem Production Competition for	Probability
9 or 10 of 12 with system competition and 0 or 1 of 6 without system competition	1.8%

II-4. The statistical significance of the relationships between whether or not the munition was new or modified and whether or not there was subsystem production competition or low-rate initial production phases was calculated from Fisher's exact probability test for a 2x2 contingency table with small sample sizes:

Subsystem Production Competition for	Probability
1 or 2 of 8 new and 9 or 8 of 9 modified	1.3%

Low-Rate Initial Production Phase for	Probability
7 or more of 9 new and 2 or fewer of 10 modified	1.9%

II-5. The statistical significance of the relationships between military service, missile type, and whether or not there was multi-year contracting was calculated from Fisher's exact probability test for a 2x2 contingency table with small sample sizes:

Multi-Year Contracting for	Probability
5 of 7 Army and 0 of 11 other services	0.2%
0 of 12 AGM + AIM and 5 of 6 other munitions	0.1%

III-1. The statistical significance of the relationships between whether or not there was a substantial change to the threat and whether or not there was an advanced development (AD) phase, prototypes during advanced development, independent testing, independent cost estimates, and system warranties was calculated from Fisher's exact probability test for a 2x2 contingency table with small sample sizes:

Advanced Development for	Probability
2 of 2 with changed threats and 10 of 17 other munitions	38.6%

Prototypes During Advanced Development for	Probability
2 of 2 with changed threats and 8 of 9 other munitions with AD phases	81.8%

Independent Testing for	Probability
2 of 2 with changed threats and 1 of 15 other munitions	2.2%

Independent Cost Estimates for	Probability
2 of 2 with changed threats and 4 of 14 other munitions	12.5%

System Warranties for	Probability
2 of 2 with changed threats and 4 of 14 other munitions	12.5%

III-2. The statistical significance of the relationships between the required level of technological advance and each category of munition was calculated from Fisher's exact probability test for a 2x2 contingency table with small sample sizes:

Extensive Performance Advances for	Probability
4 or 5 intercept and 2 or fewer of 4 surface attack	17.5%
3 or fewer of 6 air launched and 3 or more of 5 surface launched	60.8%
5 or 6 of 7 new and 1 or 0 of 4 modified	19.7%

Extensive Material Advances for	Probability
0 or 1 of 5 intercept and 4 or 3 of 6 surface attack	34.8%
2 or fewer of 6 air launched and 2 or more of 5 surface launched	80.3%
2 or fewer of 7 new and 2 or more of 4 modified	91.2%

Extensive Production Advances for	Probability
0 or 1 of 5 intercept and 3 or 2 of 6 surface attack	57.6%
0 or 1 of 6 air launched and 3 or 2 of 5 surface launched	42.4%
2 or 3 of 7 new and 1 or 0 of 4 modified	72.1%

Substantial or Extensive Performance Advances for	Probability
5 of 5 intercept and 5 of 6 surface attack	54.5%
5 of 6 air launched and 5 of 5 surface launched	54.5%
6 of 7 new and 4 of 4 modified	63.6%

Substantial or Extensive Materials Advances for	Probability
5 of 5 intercept and 5 of 6 surface attack	54.5%
4 of 6 air launched and 5 of 5 surface launched	27.3%
6 or 7 of 7 new and 3 or 2 of 4 modified	89.1%

Substantial or Extensive Production Advances for	Probability
3, 4 or 5 of 5 intercept and 6, 5, or 4 of 6 surface attack	81.8%
4, 5, or 6 of 6 air launched and 5, 4, or 3 of 5 surface launched	81.8%
7 of 7 new and 2 of 4 modified	10.9%

III-3. The numbers of new and modified munitions for each level of required performance and materials technology advance are shown in the first table below. The numbers of new and modified munitions for each level of required performance and production technology advance are shown in the second table below. The munitions are separated into new and modified in these tables because of the differences in performance technology requirements between new and modified munitions.

Numbers of Munitions in the Sample for Each Level of Required Performance and Materials Technology

New — Performance \ Materials	Off-the-Shelf	Minor	Sub-stantial	Exten-sive	All New	Total
Off-the-Shelf						
Minor		1				1
Substantial			1			1
Extensive			3	2		5
All New						
Total		1	4	2		7

Modified — Performance \ Materials	Off-the-Shelf	Minor	Sub-stantial	Exten-sive	All New	Total
Off-the-Shelf						
Minor						
Substantial	1		1	1		3
Extensive				1		1
All New						
Total	1		1	2		4

Numbers of Munitions in the Sample for Each Level of Required Performance and Production Technology

New — Performance \ Materials	Off-the-Shelf	Minor	Sub-stantial	Exten-sive	All New	Total
Off-the-Shelf						
Minor			1			1
Substantial			1			1
Extensive			3	2		5
All New						
Total			5	2		7

Modified — Performance \ Materials	Off-the-Shelf	Minor	Sub-stantial	Exten-sive	All New	Total
Off-the-Shelf						
Minor						
Substantial		2	1			3
Extensive				1		1
All New						
Total		2	1	1		4

III-4. The statistical significance of the relationships between the required levels of technological advance and whether or not each of the acquisition policies were applied was calculated from Fisher's exact probability test for a 2x2 contingency table with small sample sizes:

Extensive Performance Advances for	Probability
5 or 6 of 8 with AD and 1 or 0 of 3 without AD	42.4%
4 or 5 of 5 with AD and 1 or 0 of 3 with non-competitive AD	28.6%
4 of 6 with prototypes in AD and 0 of 1 without prototypes in AD	≥42.9%
0 of 2 with FSD subsystem competition and 6 of 9 without FSD subsystem competition	18.2%
2 or 3 of 3 with independent testing and 2 or 1 of 6 without independent testing	40.5%
0 of 2 with independent cost estimates and 4 of 7 without independent cost estimates	35.7%
4 or 3 of 7 with low rate initial production phase and 2 or 3 of 3 without low rate initial production phase	66.7%
2 or fewer of 4 with competitive system production and 4 or more of 6 with non-competitive system production	≥42.9%
2 of 6 with competitive subsystem production and 4 of 4 with non-competitive subsystem production	7.1%
2 or 1 of 4 with system warranties and 4 or 5 of 5 without system warranties	40.5%
2 of 2 with subsystem warranties and 3 of 5 without subsystem warranties	35.7%

Substantial or Extensive Performance Advances for	Probability
7 of 8 with AD and 3 of 3 without AD	72.7%
4 of 5 with competitive AD and 3 of 3 with non-competitive AD	62.5%
5 of 6 with prototypes in AD and 1 of 1 without prototypes in AD	85.7%
1 of 2 with subsystem competition in FSD and 9 of 9 without subsystem competition in FSD	18.2%
3 of 3 with independent testing and 5 of 6 without independent testing	66.7%
5 of 6 with independent cost estimates and 2 of 2 without independent cost estimates	75.0%
6 of 7 with low rate initial production phase and 3 of 3 without low rate initial production phase	70.0%
3 of 4 with system production competition and 6 of 6 without system production competition	40.0%
5 of 6 with subsystem production competition and 4 of 4 without subsystem production competition	60.0%
4 of 4 with system warranties and 5 of 5 without subsystem warranties	100.0%
2 of 2 with subsystem warranties and 6 of 6 without subsystem warranties	100.0%

Extensive Materials Advances for	Probability
3 or fewer of 8 with AD and 1 or more of 3 without AD	72.1%
2 or 3 of 5 with competitive AD and 1 or 0 of 3 with non-competitive AD	71.4%
3 of 6 with prototypes in AD and 0 of 1 without prototypes in AD	57.1%
1 or 2 of 2 with FSD subsystem competition and 3 or 2 of 9 without FSD subsystem competition	89.1%

2 or 3 of 3 with independent testing and 1 or 0 of 6 without independent testing	22.6%
3 of 6 with independent cost estimates and 0 of 2 without independent cost estimates	35.7%
3 or 4 of 7 with low rate initial production phases and 1 or 0 of 3 *without low rate initial production phases*	66.7%
2 or more of 4 with competitive system production and 2 or fewer of 6 with non-competitive system production	≥54.8%
3 or 4 of 6 with competitive subsystem production and 1 or 0 of 4 with non-competitive subsystem production	45.2%
3 or 4 of 4 with system warranties and 1 or 0 of 5 without system warranties	16.7%
2 of 2 with subsystem warranties and 2 of 6 without subsystem warranties	21.4%

<u>Substantial or Extensive Materials Advances for</u>	<u>Probability</u>
7 or 8 of 8 with AD and 1 or 0 of 3 without AD	≥49.1%
4 of 5 with competitive AD and 3 of 3 with non-competitive AD	62.5%
5 of 6 with prototypes during AD and 1 of 1 without prototypes during AD	85.7%
1 or 0 of 2 with FSD subsystem competition and 8 or 9 of 9 without FSD subsystem competition	≥34.5%
3 of 3 with independent testing and 4 of 6 without independent testing	41.7%
5 or 6 of 6 with independent cost estimates and 1 or 0 of 2 without independent cost estimates	96.4%
5 of 7 with low rate initial production phases and 3 of 3 without low rate initial production phases	46.7%
4, 3 or 2 of 4 with competitive system production and 4, 5 or 6 of 6 with non-competitive system production	86.7%
4 of 6 with competition *subsystem production and 4 of 4 with non-*competitive subsystem production	33.3%
3 of 4 with system warranties and 5 of 5 without system warranties	44.4%
2 of 2 with subsystem warranties and 5 of 6 without subsystem warranties	75.0%

<u>Extensive Production Advances for</u>	<u>Probability</u>
2 or fewer of 8 with AD and 1 or more of 3 without AD	84.8%
2 of 5 with competitive AD and 0 of 3 with non-competitive AD	35.7%
2 of 6 with prototypes in AD and 0 of 1 without prototypes in AD	71.4%
0 of 2 with FSD subsystem competition and 3 of 9 without FSD subsystem competition	50.9%
1 or 2 of 3 with independent testing and 1 or 0 of 6 without independent testing	91.7%
2 of 6 with independent cost estimates and 0 of 2 without independent cost estimates	53.6%
2 or fewer of 7 with low rate initial production phases and 1 or more of 3 without low rate initial production phases	81.7%
1 or 0 of 4 with competitive system production and 2 or 3 of 6 with non-competitive system production	66.7%
2 or 3 of 6 with competitive subsystem production and 1 or 0 of 4 with non-competitive subsystem production	66.7%
2 or 3 of 4 with system warranties and 1 or 0 of 5 without system warranties	40.5%
2 of 2 with subsystem warranties and 1 of 6 without subsystem warranties	10.7%

Substantial or Extensive Production Advances for	Probability
8 of 8 with AD and 1 of 3 without AD	5.5%
5 of 5 with competitive AD and 3 of 3 with non-competitive AD	100.0%
6 of 6 with prototypes in AD and 1 of 1 without prototypes in AD	100.0%
2 of 2 with FSD subsystem competition and 7 of 9 without FSD subsystem competition	65.5%
3 of 3 with independent testing and 4 of 6 without independent testing	41.7%
6 of 6 with independent cost estimates and 0 of 2 without independent cost estimates	3.6%
6 or 7 or 7 with low rate initial production phases and 1 or 0 of 3 without low rate initial production phases	93.3%
4 of 4 with competitive system production and 4 of 6 with non-competitive system production	33.3%
4 of 6 with competitive subsystem production and 4 of 4 with non-competitive subsystem production	33.3%
4, 3 or 2 of 4 with system warranties and 3, 4, or 5 of 5 without system warranties	83.3%
2 of 2 with subsystem warranties and 4 of 6 without subsystem warranties.	53.6%

III-5. c.f. III-4.

III-6. c.f. III-4.

III-7. The quantitative data provided by the contractors show five differences (out of a maximum possible of thirty-three) between the anticipated and actual levels of required technology advance. Two of the differences were for one of the new munitions, and were for anticipated off-the-shelf performance and materials technology advance requirements and actual minor technology advance requirements. Two more of the differences were for another munition, for anticipated substantial performance advance and minor production advance requirements and actual extensive technology advance requirements. The final difference was for anticipated substantial performance advances and actual extensive performance advances.

III-8. The data for Figures III-2 through III-4 are:

Resource	Characteristic	Sample Size	Low	High	Mean	Statistical Significance	Test
Test Equipment	Total Sample	11	15	100	83		
Test Equipment	Intercept	5	67	100	85	.662	Mann-Whitney
Test Equipment	Surface Attack	6	15	100	82		
Test Equipment	Air Launched	6	75	100	93	.178	Mann-Whitney
Test Equipment	Surface Launched	5	15	100	71		
Test Equipment	Army	5	15	100	71		
Test Equipment	Navy	4	75	100	94	>.100	Kruskal-Wallis
Test Equipment	Air Force	2	90	95	93		
Test Equipment	New	7	85	100	96	.018	Mann-Whitney
Test Equipment	Modified	4	15	90	62		
Facilities	Total Sample	11	0	100	50		
Facilities	Intercept	5	10	30	17	.082	Mann-Whitney
Facilities	Surface Attack	6	0	100	78		
Facilities	Air Launched	6	10	100	53	.428	Mann-Whitney
Facilities	Surface Launched	5	0	100	47		
Facilities	Army	5	0	100	47		
Facilities	Navy	4	10	100	56	>.100	Kruskal-Wallis
Facilities	Air Force	2	10	80	45		
Facilities	New	7	10	100	62	.230	Mann-Whitney
Facilities	Modified	4	0	80	29		
Tooling	Total Sample	11	0	100	75		
Tooling	Intercept	5	0	100	66	.482	Mann-Whitney
Tooling	Surface Attack	6	15	100	83		
Tooling	Air Launched	6	0	100	80	.599	Mann-Whitney
Tooling	Surface Launched	5	15	100	69		
Tooling	Army	5	15	100	69		
Tooling	Navy	4	0	100	75	>.100	Kruskal-Wallis
Tooling	Air Force	2	80	100	90		
Tooling	New	7	80	100	97	.009	Mann-Whitney
Tooling	Modified	4	0	80	36		

III-9. Spearman rank correlations between resource requirements and development start dates are shown below:

Resources	Correlation Coefficient	Significance Level
Test Equipment Requirements	–.293	33.1%
Facilities Requirements	–.173	56.7%
Tooling Requirements	.000	100.0%

III-10. Spearman rank correlations between the three categories of resource requirements are shown below:

Resources		Correlation Coefficient	Significance Level
Test Equipment Requirements	Facilities Requirements	+.516	8.7%
Test Equipment Requirements	Tooling Requirements	+.736	1.5%
Facilities Requirements	Tooling Requirements	+.445	14.0%

III-11. The data for Figure III-5 are:

Resource	Technology	Advance Level	Sample Size	Low	High	Mean	Statistical Significance	Test
Test Equipment	Performance	Minor	1	100	100	100		
Test Equipment	Performance	Substantial	4	15	100	70	.405	Kruskal-Wallis
Test Equipment	Performance	Extensive	6	67	100	90		
Test Equipment	Materials	Off-the-Shelf	1	75	75	75		
Test Equipment	Materials	Minor	1	100	100	100	.500	Kruskal-Wallis
Test Equipment	Materials	Substantial	5	15	100	80		
Test Equipment	Materials	Extensive	4	67	100	86		
Test Equipment	Production	Minor	2	15	75	45	.072	Mann-Whiteny
Test Equipment	Production	Substantial	6	90	100	96	.321	Mann-Whitney
Test Equipment	Production	Extensive	3	67	100	84		
Facilities	Peformance	Minor	1	100	100	100		
Facilities	Performance	Substantial	4	0	100	49	.440	Kruskal-Wallis
Facilities	Performance	Extensive	6	10	100	43		
Facilities	Materials	Off-the-Shelf	1	15	15	15		
Faciliteis	Materials	Minor	1	100	100	100	.274	Kruskal-Wallis
Facilities	Materials	Substantial	5	0	100	30		
Facilities	Materials	Extensive	4	20	100	71		
Facilities	Production	Minor	2	0	15	8		
Facilities	Production	Substantial	6	10	100	55	.211	Kruskal-Wallis
Facilities	Production	Extensive	3	20	100	68		
Tooling	Performance	Minor	1	100	100	100		
Tooling	Performance	Substantial	4	0	100	49	.227	Kruskal-Wallis
Tooling	Performance	Extensive	6	50	100	88		
Tooling	Mateirals	Off-the-Shelf	1	0	0	0		
Tooling	Materials	Minor	1	100	100	100	.322	Kruskal-Wallis
Tooling	Materials	Substantial	5	15	100	79		
Tooling	Materials	Extensive	4	50	100	83		
Tooling	Production	Minor	2	0	15	8	.072	Mann-Whitney
Tooling	Production	Substantial	6	80	100	93	.904	Mann-Whitney
Tooling	Production	Extensive	3	50	100	83		

III-12. The data for Figure III-6 are shown below. All of the statistical significance tests are Mann-Whitney, interpreted using the Tables of Probabilities and Critical Values in the *Chemical Rubber Corporation Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Resource	Initiative	Sample Size	Low	High	Mean	Statistical Significance
Test Equipment	With Advanced Development Phase	8	85	100	95	.012
Test Equipment	Without Advanced Development Phase	3	15	75	52	
Facilities	With Advanced Development Phase	8	10	100	64	.134
Facilities	Without Advanced Development Phase	3	0	20	10	
Tooing	With Advanced Development Phase	8	80	100	95	.012
Tooling	Without Advanced Development Phase	3	0	50	22	
Test Equipment	With Advanced Development Prototypes	6	85	100	95	.714
Test Equipment	Without Advanced Development Prototypes	1	100	100	100	
Facilities	With Advanced Development Prototypes	6	10	100	64	.572
Facilities	Without Advanced Develpment Prototypes	1	100	100	100	
Tooling	With Advanced Development Prototypes	6	80	100	97	1.000
Tooling	Without Advanced Development Prototypes	1	100	100	100	
Test Equipment	With FSD Subsystem Competition	2	90	100	95	>.200
Test Equipment	Without FSD Subsystem Competition	9	15	100	81	
Facilities	With FSD Subsystem Competition	2	80	100	90	>.200
Facilities	Without FSD Subsystem Competition	9	0	100	41	
Tooling	With FSD Subsystem Competition	2	80	100	90	>.200
Tooling	Without FSD Subsystem Competition	9	0	100	72	
Test Equipment	With Independent Cost Estimate	6	85	100	95	.072
Test Equipment	Without Independent Cost Estimate	2	15	75	45	
Facilities	With Independent Cost Estimate	6	10	100	79	.142
Facilities	Without Independent Cost Estimate	2	0	15	8	
Tooling	With Independent Cost Estimate	6	80	100	97	.072
Tooling	Without Independent Cost Estimate	2	0	15	8	
Test Equipment	With Low Rate Initial Production Phase	7	75	100	92	.091
Test Equipment	Without Low Rate Initial Production Phase	3	15	90	57	
Facilities	With Low Rate Initial Production Phase	7	10	100	57	.384
Facilities	Without Low Rate Initial Production Phase	3	0	30	17	
Tooling	With Low Rate Initial Production Phase	7	0	100	83	.150
Tooling	Without Low Rate Initial Production Phase	3	15	80	48	
Test Equipment	With System Production Competition	4	67	100	88	.838
Test Equipment	Without System Production Competition	6	15	100	78	
Facilities	With System Production Competition	4	10	100	53	.762
Facilities	Without System Production Competition	6	0	100	40	
Tooling	With System Production Competition	4	50	100	83	.838
Tooling	Without System Production Competition	6	0	100	66	
Test Equipment	With Subsystem Production Competition	6	15	100	75	.543
Test Equipment	Without Subsystem Production Competition	4	85	100	93	
Facilities	With Subystem Production Competition	6	0	100	53	1.000
Facilities	Without Subsystem Production Competition	4	10	85	34	
Tooling	With Subsystem Production Competition	6	0	100	58	.215
Tooling	Without Subystem Production Competition	4	80	100	95	
Test Equipment	With System Warranty	4	75	100	88	.904
Test Equipment	Without System Warranty	5	15	100	73	
Test Equipment	With Subsystem Warranty	2	67	100	84	1.000
Test Equipment	Without Subsystem Warranty	6	15	100	76	

III-13. The quantitative data provided by the contractors show six differences (out of a maximum possible of thirty-three) for four separate munitions, between the anticipated and actual requirements for the three types of resources. Three of the differences were small, for three different munitions: one overestimate of percentage requirement for new test equipment by 5 percent (100 percent anticipated versus 95 percent actual); and two underestimates of the percentage requirements for new facilities by 5 percent (10 percent anticipated versus 15 percent actual, and 25 percent anticipated versus 30 percent actual). The other three differences are for large underestimates for each of the three resources for one munition: a 40-percent underestimate of the requirement for new test equipment (50 percent anticipated versus 90 percent actual); and 50-percent underestimates of the percentage requirements for both new facilities and new tooling (30 percent anticipated versus 80 percent actual).

III-14. Spearman rank correlations between the three categories of resource requirements anticipation error are shown below:

Resource Requirements Anticipation Errors		Correlation Coefficient	Significance Level
Test Equipment	Facilities	.417	>10.0%
Test Equipment	Tooling	.268	>10.0%
Facilities	Tooling	.375	>10.0%

III-15. A measure of development macro-stability was also calculated for each munition in the sample, but those measures were found to have no relationship to any of the development outcome measures evaluated in Chapter IV nor to any of the other risk measures discussed in Chapter III. The measure of development macro-stability for each munition was calculated as the compound annual growth for defense research, development, test and evaluation total obligational authority, from the start of full scale development to initial operational capability. The data are shown below:

Designator	Title	Compound Annual Growth Rate
A/RIM-7E	Sparrow III B CW	4.49
AIM-7F	Sparrow III Pulse Doppler	-2.60
A/RIM-7M	Sparrow III Monopulse	5.55
AIM-9L	Sidewinder	-0.64
AIM-9M	Sidewinder	3.78
AIM-54A	Phoenix	-3.93
AIM-54C	Phoenix	6.15
AIM-120A	AMRAAM	5.20
FIM-92A	Stinger-Basic	0.34
FIM-92A	Stinger-POST/RMP	5.60
AGM-65D/F/G	IIR Maverick	8.30
A/R/UGM-84A/C/D	Harpoon	-1.34
AGM-88A	HARM	6.65
AGM-114A/B	Hellfire	6.44
BGM-71A	TOW I	-2.86
BGM-71D	TOW II	9.83
-	MLRS	5.55
M-712	Copperhead CLGP	4.80
-	5" Deadeye SALGP	3.78
Number of Observations		19

III-16. For those years that the budgeted amount was zero, no error was calculated. Nor were any errors calculated for those years for which either the budgeted amount or appropriated amount could not be found in the SARs. In the calculation, the errors are squared, to keep the positive and negative errors from offsetting one another. The squared errors for a munition were averaged, and the square root of the average was calculated. Use of this measure weights (for example) a 50-percent cut in a small budget the same as a 50-percent cut in a large budget. An alternative micro-measure could be calculated as the root mean squared annual error, normalized by the mean annual budget; use of this latter measure would give a 50-percent cut in a small budget much less impact than a 50-percent cut in a large budget. The former measure was used because it was believed that the annual percentage error was more important to the contractor in planning and managing his program.

III-17. The data for Figure III-7 are shown below. All of the statistical tests are Kruskal-Wallis.

Category	Sample Size	Low	High	Mean	Statistical Significance
Total Sample	18	–3.99	9.79	1.81	
Intercept	10	–3.99	9.79	1.85	.789
Surface Attack	8	–3.37	9.51	2.22	
Air Launched	12	–3.99	8.49	1.20	.373
Surface Launched	6	–2.34	9.79	3.01	
Army	7	–2.34	9.79	2.56	
Air Force	2	–3.99	–3.37	–3.68	.056
Navy	9	–3.98	8.49	2.44	
New	9	–3.99	9.79	2.51	.479
Modified	9	–3.98	8.49	1.10	

III-18. The data for Figure III-8 are shown below. All of the statistical tests are Mann-Whitney, interpreted using the Table of Probabilities in the *Chemical Rubber Corporation Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Category	Sample Size	Low	High	Mean	Statistical Significance
Total Sample	11	.073	.608	.262	
Intercept	5	.073	.479	.208	.482
Surface Attack	6	.092	.608	.307	
Air Launched	8	.073	.508	.240	.702
Surface Launched	3	.119	.608	.321	
Army	4	.092	.608	.264	1.000
Navy	5	.073	.276	.167	.094
Air Force	2	.479	.508	.494	
New	6	.092	.608	.282	1.000
Modified	5	.073	.508	.237	

III-19. Spearman rank correlations between production start dates and funding stability measures are shown below:

Funding Stability Measure	Sample Size	Correlation Coefficient	Statistical Significance
Procurement TOA Growth Rate	18	−.431	7.5%
Root Mean Squared Annual Percentage Difference Between Program Procurement Requests and Appropriations	11	+.141	65.5%

III-20. Spearman rank correlations between stability measures and requirements for new resources are shown below:

Measures	Sample Size	Correlation Coefficient	Statistical Significance
Root Mean Squared Annual Percentage Difference Between Program Procurement Requests and Appropriations	11	+.086	78.5%
Procurement TOA Annual Growth Rate			
New Test Equipment	10	−.082	80.6%
New Facilities	10	+.330	32.2%
New Tooling	10	.000	100.0%
Root Mean Squared Annual Percentage Difference Between Program Procurement Requests and Appropriations			
New Test Equipment	8	−.137	>10.0%
New Facilities	8	−.012	>10.0%
New Tooling	8	+.250	>10.0%

The significance levels for the sample sizes of 8 were interpreted using the Table of Critical Values from the *Chemical Rubber Company Handbook of Tables for Probability and Statistics.*

III-21. The data for Figure III-9 are shown below. All of the statistical significance tests are Kruskal-Wallis.

Technology	Advance Level	Sample Size	Low	High	Mean	Statistical Significance
Performance	Minor	1	.092	.092	.092	>.129
Performance	Substantial	3	.122	.508	.289	
Performance	Extensive	4	.119	.608	.371	
Materials	Off-the-Shelf	1	.122	.122	.122	>.100
Materials	Minor	1	.092	.092	.092	
Materials	Substantial	3	.119	.479	.278	
Materials	Extensive	3	.276	.608	.464	
Production	Minor	2	.122	.236	.179	>.102
Production	Substantial	4	.092	.508	.300	
Production	Extensive	2	.276	.608	.442	

III-22. The data for Figure III-10 are shown below:

Initiative	Sample Size	Low	High	Mean	Statistical Significance	Test
With Limited Initial Production Phase	7	.092	.608	.315	.375	Mann-Whitney
Without Limited Initial Production Phase	1	.119	.119	.119		
With Competitive System Production	5	.073	.508	.280	.930	Mann-Whitney
Without Competitive System Production	6	.122	.608	.247		
With Competitive Subsystem Production	7	.073	.508	.222	.648	Mann-Whitney
Without Competitive Subsystem Production	4	.119	.608	.331		
With Multi-year Production Contracting	2	.236	.608	.422	>.200	Mann-Whitney
Without Multi-year Production Contracting	9	.073	.508	.226		
With Foreign Production	3	.119	.508	.369	.630	Mann-Whitney
Without Foreign Production	8	.073	.608	.256		

III-23. The development/production overlap ratio calculation data for Table III-5 are shown below. The IOC, MS II, and MS III dates are from Table II-1.

Designator	Title	IOC	MS II	MS III	IOC-MS III	IOC-MS II
A/RIM-7E	Sparrow III-B CW	12/63	1/60	I.U.	I.U.	47
AIM-7F	Sparrow III Pulse Doppler	4.76	12/65	I.U.	I.U.	124
A/RIM-7M	Sparrow III Monopulse	1/83	4/78	11/82	2	54
AIM-9L	Sidewinder	5/78	8/71	1/76	28	81
AIM-9M	Sidewinder	9/82	2/76	6/81	19	79
AIM-54A	Phoenix	12/73	I.U.	I.U.	I.U.	I.U.
AIM-54C	Phoenix	12/86	10/76	12/79	84	122
AIM-120A	AMRAAM	10/89	11/82	3/89	6	83
FIM-92A	Stinger	2/81	5/72	11/77	39	105
FIM-92A	Stinger-POST/RMP	I.U.	I.U.	I.U.	I.U.	I.U.
AGM-65D/F/G	IIR Maverick	2/86	9/76	9/82	41	120
A/R/UGM-84A/C/D	Harpoon	7/77	3/74	6/75	25	40
AGM-88A/B	HARM	11/83	2/78	3/83	8	69
AGM-114A/B	Hellfire	7/86	2/76	3/82	52	125
BGM-71A	TOW I	9/70	I.U.	I.U.	I.U.	I.U.
BGM-71D	TOW II	10/83	9/78	9/81	25	61
–	MLRS	3/83	N.A.	5/80	34	N.A.
M-712	Copperhead CLGP	12/82	6/75	11/79	37	70
–	5" Deadeye SALGP	N.A.	11/77	N.A.	N.A.	N.A.

I.U. - Information unavailable.
N.A. - Not applicable.

The development/production overlap ratios in Table III-5 are highly correlated with the numbers of months between MS III and IOC; the Spearman rank correlation is .738 with a statistical significance of 01.4%, which means that a high development/production overlap ratio is indicative of a larger number of months of overlap, but not of a shorter development schedule.

III-24. The data for Figure III-11 are shown below. The **Mann-Whitney** tests are interpreted using the Tables of Probabilities and Critical **Values in the** *Chemical Rubber Corporation Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Characteristic	Sample Size	Low	High	Mean	Statistical Significance	Test
Total Sample	12	.037	.689	.350		
Intercept	6	.037	.689	.293	.310	Mann-Whitney
Surface Attack	6	.116	.625	.406		
Air Launched	10	.037	.689	.326	>.200	Mann-Whitney
Surface Launched	2	.410	.529	.470		
Army	4	.371	.529	.432	.264	Kruskall-Wallis
Navy	6	.037	.689	.342		
Air Force	2	.072	.342	.207		
New	6	.072	.625	.355	.700	Mann-Whitney
Modified	6	.037	.689	.344		

III-25. Spearman rank correlations between the development/production overlap ratios and production start dates and funding stability measures are shown below:

Measure	Sample Size	Correlation Coefficient	Statistical Significance
Production Start Date	12	–.580	5.4%
Procurement TOA Annual Growth Rate	12	+.525	8.2%
Root Mean Squared Annual Percentage Difference Between Program Procurement Requests and Appropriations	11	–.059	85.2%

III-26. Spearman rank correlations between the development/production overlap ratios and the percentage requirements for new resources are shown below:

Resource Category	Sample Size	Correlation Coefficient	Statistical Significance
Requirements for New Test Equipment	8	–.512	>10.0%
Requirements for New Facilities	8	+.048	>10.0%
Requirements for New Tooling	8	–.238	>10.0%

The significance levels were interpreted using the Table of Critical Values from the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small sample sizes.

III-27. The data for Figure III-12 are shown below. All of the statistical tests are Kruskal-Wallis.

Technology	Advance Level	Sample Size	Low	High	Mean	Statistical Significance	Test
Performance	Minor	1	.416	.416	.416		
Performance	Substantial	3	.342	.689	.480	>.129	Kruskal-Wallis
Performance	Extensive	4	.072	.529	.272		
Materials	Off-the-Shelf	1	.689	.689	.689		
Materials	Minor	1	.416	.416	.416	.359	Kruskal-Wallis
Materials	Substantial	3	.072	.410	.284		
Materials	Extensive	3	.116	.529	.329		
Production	Minor	2	.410	.689	.550		
Production	Substantial	4	.072	.416	.300	>.105	Kruskal-Wallis
Production	Extensive	2	.116	.529	.323		

III-28. The data for Figure III-13 are shown below. All of the statistical significance tests are Mann-Whitney, interpreted using the Table of Probabilities in the *Chemical Rubber Corporation Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Initiatives	Sample Size	Low	High	Mean	Statis-tical Signifi-cance	Test
With Independent Testing	2	.116	.342	.229	>.200	Mann-Whitney
Without Independent Testing	9	.037	.689	.374		
With Independent Cost Estimate	5	.072	.529	.295	.662	Mann-Whitney
Without Independent Cost Estimate	6	.037	.689	.391		
With Low-Rate Initial Production Phase	7	.072	.689	.398	.834	Mann-Whitney
Without Low-Rate Initial Production Phase	3	.346	.410	.376		
With System Production Competiton	6	.037	.416	.242	.064	Mann-Whitney
Without System Competition	6	.116	.625	.457		

IV-1. The statistical significance of the relationships between munition category and whether or not the munition satisfied the operational and technical requirements was calculated from Fisher's exact probability test for a 2x2 contingency table with small sample sizes:

Operational and Technical Requirements Satisfied by	Probability
3 or fewer of 8 intercept and 4 or more of 9 surface attack	58.1%
3 or fewer of 11 air-launched and 4 or more of 6 surface-launched	14.5%
3 or fewer of 9 new and 4 or more of 8 modified	41.9%

IV-2. A test using the Table of the Total Number-of-Runs Test for Randomness in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal sample sizes was performed to test whether or not satisfaction of operational and technical requirements is randomly distributed over time. There are nine runs in the data. The probability of nine or fewer runs with samples of seven munitions satisfying the requirements and 10 munitions not satisfying the requirements is equal to .549.

IV-3. The statistical significance of the relationships between whether or not an acquisition policy was applied and whether or not the munition satisfied the operational and technical requirements was calculated from Fisher's exact probability test for a 2x2 contingency table with small sample sizes:

Operational and Technical Requirements Satisfied by	Probability
4 or fewer of 7 with AD and 7 or more of 10 without AD	85.5%
0 of 4 with competitive AD and 5 of 7 with non-competitive AD	19.7%
2 or fewer of 6 with prototypes in AD and 7 or more of 10 without prototypes in AD	18.2%
1 or 0 of 7 with FSD subsystem competition and 3 or 4 of 9 without FSD subsystem competition	39.2%
1 or 0 of 6 with independent testing and 2 or 3 of 10 without independent testing	69.6%
3 or more of 6 with independent cost estimates and 2 or fewer of 9 without independent cost estimates	28.7%
3 or fewer of 6 with low-rate initial production phases and 5 or more of 8 without low-rate initial production phases	52.9%

IV-4. The statistical significance of the relationships between technology advance and whether or not the munition satisfied the operational and technical requirements was calculated from Fisher's exact probability test for a 2x2 contingency table with small sample sizes:

Operational and Technical Requirements Satisfied by	Probability
2 or 1 of 5 with extensive advances and 4 or 5 with substantial or lesser advances in performance technology	40.5%
2 or fewer of 3 with extensive advances and 4 or more of 6 with substantial or lesser advances in materials technology	77.4%
1 or 0 of 2 with extensive advances and 5 or 6 of 7 with substantial or lesser advances in production technology	91.7%

IV-5. The data for Figure IV-1 are shown below. The Mann-Whitney tests were interpreted using the Table of Probabilities from the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Resource	Requirements Satisfied	Sample Size	Low	High	Mean	Statistical Significance	Test
Test Equipment	Yes	6	15	100	76	.072	Mann-Whitney
Test Equipment	No	3	100	100	100		
Facilities	Yes	6	0	100	52	.548	Mann-Whitney
Facilities	No	3	10	100	70		
Tooling	Yes	6	0	100	63	.166	Mann-Whitney
Tooling	No	3	100	100	100		

IV-6. The data for Figure IV-2 are shown below:

Requirement Satisfied	Sample Size	Low	High	Mean	Statistical Significance	Test
Yes	5	.342	.689	.468	.246	Mann-Whitney
No	6	.037	.625	.297		

IV-7. The data for Figure IV-3 are shown below:

Measure	Characteristic	Sample Size	Low	High	Mean
Advanced Development	All–Actual	9	17	75	42
Full Scale Development	All–Planned	19	33	127	57
Full Scale Development	All–Actual	19	47	134	85
Full Scale Development	Intercept–Planned	10	33	127	62
Full Scale Development	Intercept–Actual	10	47	134	90
Full Scale Development	Surface Attack–Planned	9	37	87	59
Full Scale Development	Surface Attack–Actual	9	49	125	80
Full Scale Development	Air Launched–Planned	12	33	87	55
Full Scale Development	Air Launched–Actual	12	47	125	85
Full Scale Development	Surface Launched–Planned	7	49	127	69
Full Scale Development	Surface Launched–Actual	7	49	134	85
Full Scale Development	Army–Planned	7	52	127	74
Full Scale Development	Army–Actual	7	61	134	96
Full Scale Development	Navy–Planned	10	33	84	52
Full Scale Development	Navy–Actual	10	47	124	73
Full Scale Development	Air Force–Planned	2	54	57	56
Full Scale Development	Air Force–Actual	2	94	113	104
Full Scale Development	New–Planned	10	37	87	58
Full Scale Development	New–Actual	10	49	125	80
Full Scale Development	Modified–Planned	9	33	127	63
Full Scale Development	Modified–Actual	9	47	134	91

IV-8. The data for Figure IV-4 are shown below. The Mann-Whitney test was interpreted using the Table of Probabilities in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Characteristic	Sample Size	Low	High	Mean	Statistical Significance	Test
Total Sample	19	1.00	2.82	1.48		
Intercept	10	1.00	2.82	1.58	.462	Kruskal-Wallis
Surface Attack	9	1.00	1.98	1.36		
Air Launched	12	1.00	2.82	1.59	.271	Kruskal-Wallis
Surface Launched	7	1.00	1.73	1.28		
Navy	10	1.00	2.82	1.49	.845	Kruskal-Wallis
Army	7	1.00	1.73	1.34	.056	Mann-Whitney
Air Force	2	1.74	1.98	1.86		
New	10	1.00	1.74	1.38	.744	Kruskal-Wallis
Modified	9	1.00	2.82	1.58		
Operational/Technical Requirements Satisfied	7	1.00	1.98	1.40	.845	Kruskal-Wallis
Operational/Technical Requirements not Satisfied	10	1.00	2.82	1.54		

IV-9. The data for Figure IV-5 are shown below. The Mann-Whitney tests were interpreted using the Tables of Probabilities and Critical Values in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Initiative	Sample Size	Low	High	Mean	Statistical Significance	Test
With Advanced Development Phase	12	1.00	1.98	1.44	.672	Kruskal-Wallis
Without Advanced Development Phase	7	1.00	2.82	1.54		
With Advanced Development Prototypes	10	1.00	1.98	1.46	.327	Kruskal-Wallis
Without Advanced Development Prototypes	8	1.00	2.82	1.48		
With Competitive Advanced Development	7	1.00	1.74	1.44	.816	Mann-Whitney
With Non-Competitive Advanced Development	5	1.00	1.98	1.43		
With FSD Subsystem Competition	4	1.35	1.98	1.57	>.200	Mann-Whitney
Without FSD Subsystem Competition	14	1.00	2.82	1.48		
With Independent Testing	3	1.19	1.98	1.46	>.200	Mann-Whitney
Without Independent Testing	14	1.00	2.82	1.50		
With Independent Cost Estimate	6	1.00	1.98	1.52	.664	Kruskal-Wallis
Without Independent Cost Estimate	10	1.00	2.82	1.51		
With System Warranties	6	1.21	2.82	1.78	.039	Kruskal-Wallis
Without System Warranties	10	1.00	1.74	1.25		
With Subystem Warranties	3	1.01	1.21	1.09	>.200	Mann-Whitney
Without Subsystem Warranties	12	1.00	2.82	1.51		

IV-10. The data for Figure IV-6 are shown below. The Mann-Whitney test was interpreted using the Table of Critical Values in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Risk Measure	Sample Size	Low	High	Mean	Statistical Significance	Test
Stable Threat	17	1.00	2.82	1.46	>.200	Mann-Whitney
Unstable Threat	2	1.21	1.98	1.60		
Technology Advance Subsample	11	1.00	1.98	1.41	.934	Kruskal-Wallis
Remainder of Sample	8	1.00	2.82	1.58		
Minor Performance Advance	1	1.44	1.44	1.44	.843	Kruskal-Wallis
Substantial Performance Advance	4	1.00	1.98	1.36		
Extensive Performance Advance	6	1.06	1.74	1.43		
No Materials Advance	1	1.45	1.45	1.45	.823	Kruskal-Wallis
Minor Materials Advance	1	1.44	1.44	1.44		
Substantial Materials Advance	5	1.00	1.74	1.32		
Extensive Materials Advance	4	1.06	1.98	1.50		
Minor Production Advance	2	1.02	1.45	1.24	.711	Kruskal-Wallis
Substantial Production Advance	6	1.00	1.98	1.50		
Extensive Production Advance	3	1.06	1.73	1.33		
Develop./Prod. Overlap Subsample	12	1.01	2.45	1.54	.108	Mann-Whitney
Remainder of Sample	7	1.00	2.82	1.37		

Since the technological advance subsample and the development/production overlap subsample (both discussed in Chapter III) are not significantly different from the remainder of the sample, as shown above and in Figure IV-6, they are representative of the entire sample; inferences drawn about these two subsamples should be applicable to the entire sample. Since the resource requirements were obtained from the same representative subsample of munitions as were the required levels of technological advance, any inferences drawn about the resource requirements subsample should also be applicable to the entire sample.

IV-11. Spearman rank correlations of development schedule growth factors with the percentage requirements for new test equipment, facilities, and tooling are shown below:

Measure	Sample Size	Correlation Coefficient	Statistical Significance
Percentage Requirements for New Resources			
Test Equipment	11	.000	100.0%
Facilities	11	+.009	97.7%
Tooling	11	+.064	84.0%

IV-12. Spearman rank correlations of development schedule growth factors with development start dates and with the development/production overlap ratios described in Chapter III are shown below:

Measure	Sample Size	Correlation Coefficient	Statistical Significance
Start of Full Scale Development	19	–.116	62.3%
Concurrency Ratio	12	+.119	69.3%

IV-13. Spearman rank correlations of the number of months in advanced development with the number of months in full scale development and the development schedule growth factors are shown below. Statistical significance was interpreted using the Table of Critical Values from the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small sample sizes.

Measure	Sample Size	Correlation Coefficient	Statistical Significance
Number of Months in Full Scale Development	9	+.125	>10.0%
Development Schedule Growth Factor	9	+.038	>10.0%

IV-14. The data for Figure IV-7 are shown below:

Characteristic	Sample Size	Low	High	Mean
All–Planned	19	29	654	158
All–Actual	19	29	472	148
Intercept–Planned	10	29	222	72
Intercept–Actual	10	29	179	88
Surface Attack–Planned	9	35	654	254
Surface Attack–Actual	9	33	472	214
Air Launched–Planned	12	30	241	74
Air Launched–Actual	12	33	229	90
Surface Launched–Planned	7	29	654	302
Surface Launched–Actual	7	29	470	246
Army–Planned	7	29	654	305
Army–Actual	7	29	470	259
Navy–Planned	10	30	218	67
Navy–Actual	10	37	141	85
Air Force–Planned	2	35	169	102
Air Force–Actual	2	33	111	72
New–Planned	10	45	654	258
New–Actual	10	37	472	211
Modified–Planned	9	29	113	48
Modified–Actual	9	29	134	78

IV-15. The data for Figure IV-8 are shown below. The Mann-Whitney test was interpreted using the Table of Probabilities in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Characteristic	Sample Size	Low	High	Mean	Statistical Significance	Test
All	19	0.65	4.10	1.31		
Intercept	10	0.66	4.10	1.68	.147	Kruskal-Wallis
Surface Attack	9	0.65	1.01	0.89		
Air Launched	12	0.66	4.10	1.57	.103	Kruskal-Wallis
Surface Launched	7	0.65	1.01	0.85		
Navy	10	0.65	4.10	1.70	.890	Kruskal-Wallis
Army	7	0.72	1.01	0.90	.334	Mann-Whitney
Air Force	2	0.66	0.94	0.80		
New	19	0.65	1.01	0.84	.006	Kruskal-Wallis
Modified	9	0.94	4.10	1.83		
Operational/Technical Requirements Satisfied	7	0.65	1.50	0.96	.139	Kruskal-Wallis
Operational/Technical Requirements not Satisfied	10	0.72	4.10	1.65		

IV-16. Spearman rank correlations of development quantity growth factors with development schedule growth factors and full scale development start dates are shown below. Statistical significance for the modified sample (of size 9) was interpreted using the Table of Critical Values from the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small sample sizes.

Measure	Sample Size	Correlation Coefficient	Statistical Significance
Development Schedule Growth–All	19	+.205	38.4%
Development Schedule Growth–New	10	+.073	82.7%
Development Schedule Growth–Modified	9	+.317	>10.0%
Full Scale Development Start Date	19	–.403	8.8%

IV-17. The data for Figure IV-9 are shown on the next page. The Mann-Whitney tests were interpreted using the Tables of Probabilities and Critical Values in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Initiative	Sample Size	Low	High	Mean	Statistical Significance	Test
With Advanced Development Phase	12	0.65	1.01	0.86	.003	Kruskal-Wallis
Without Advanced Development Phase	7	1.00	4.10	2.07		
With Advanced Development Prototypes	10	0.66	1.01	0.89	.042	Kruskal-Wallis
Without Advanced Development Prototypes	8	0.65	4.10	1.89		
With Competitive Advanced Development	7	0.66	1.01	0.87	.638	Mann-Whitney
With Non-competitive Advanced Development	5	0.65	1.00	0.84		
With FSD Subsystem Competition	4	0.94	1.01	0.98	>.200	Mann-Whitney
Without FSD Subsystem Competition	14	0.65	4.10	1.44		
With Independent Testing	3	0.82	1.00	0.92	>.200	Mann-Whitney
Without Independent Testing	14	0.65	4.10	1.45		
With Independent Cost Estimate	6	0.65	1.00	0.83	.008	Kruskal-Wallis
Without Independent Cost Estimate	10	0.72	4.10	1.72		
With System Warranties	6	0.78	3.94	1.53	.436	Kruskal-Wallis
Without System Warranties	10	0.66	1.94	1.00		
With Subystem Warranties	3	1.00	1.94	1.31	>.200	Mann-Whitney
Without Subsystem Warranties	12	0.72	3.94	1.21		

The sample of munitions was furthei stratified, as shown below, in an unsuccessful attempt to separate out the effects of advanced development (with or without prototypes) from whether the munition was new or modified. None of the tests are statistically significant, and the data are not plotted in Figure IV-9.

Initiative	Sample Size	Low	High	Mean	Statistical Significance	Test
With Advanced Development Phase						
New Munitions	10	0.65	1.00	0.84	>20.0%	Mann-Whitney
Modified Munitions	2	0.94	1.00	0.97		
With Advanced Development Prototypes						
New Munitions	8	0.66	1.01	0.87	71.2%	Mann-Whitney
Modified Munitions	2	0.94	1.00	0.97		
Without Advanced Development Prototypes						
New Munitions	1	0.65	0.65	0.65	25.0%	Mann-Whitney
Modified Munitions	7	1.00	4.10	2.07		
New Munitions						
With Advanced Development Prototypes	8	0.66	1.01	0.87	22.2%	Mann-Whitney
Without Advanced Development Prototypes	1	0.65	0.65	0.65		
Modified Munitions						
With Advanced Development Phase & Advanced Development Prototypes	2	0.94	1.00	0.97	16.7%	Mann-Whitney
Without Advanced Development Phase or Advanced Development Prototypes	7	1.00	4.10	2.07		

IV-18. The data for Figure IV-10 are shown below. The Mann-Whitney test was interpreted using the Table of Critical Values in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Risk Factor	Sample Size	Low	High	Mean	Statistical Significance	Test
Stable Threat	17	0.65	4.19	1.35	>.200	Mann-Whitney
Unstable Threat	2	0.94	1.00	0.97		
Technology Advance Subsample	11	0.65	1.50	0.92	.026	Kruskal-Wallis
Remainder of Sample	8	0.72	4.10	1.84		
Develop./Prod. Overlap Subsample	12	0.66	4.10	1.31	.731	Kruskal-Wallis
Remainder of Sample	7	0.65	3.94	1.31		

IV-19. The Spearman rank correlation of development quantity growth factors with the development/production overlap ratios described in Chapter III is shown below:

Risk Measure	Sample Size	Correlation Coefficient	Statistical Significance
Concurrency Ratio	12	+.070	81.7%

IV-20. The cost per R&D round in millions of 1989 dollars is the quotient of the actual or currently planned development costs in 1989 dollars shown in Table IV-7 divided by the actual or currently planned numbers of test articles shown in Table IV-6.

IV-21. The planned and actual development costs in 1989 dollars shown in Table IV-7 for each munition are based on the then-year costs shown in the individual munition case studies contained in Volume II of this report. Those costs were divided by escalation factors to obtain the development costs in 1989 dollars. The escalation factors are from the Office of the Assistant Secretary of Defense (Comptroller) and are shown on the next page.

Designator	Title	Escalation Factor
A/RIM-7E	Sparrow III-B CW	0.29805
AIM-7F	Sparrow III Pulse Doppler	0.29805
A/RIM-7M	Sparrow III Monopulse	0.56708
AIM-9L	Sidewinder	0.33528
AIM-9M	Sidewinder	1.00000
AIM-54A	Phoenix	0.26134
AIM-54C	Phoenix	0.52415
AIM-120A	AMRAAM	0.56798
FIM-92A	Stinger-Basic	0.35122
FIM-92A	Stinger-POST/RMP	0.35122
AGM-65D/F/G	IIR Maverick	0.45075
A/R/UGM-84A/C/D	Harpoon	0.32150
AGM-88A	HARM	0.56708
AGM-114A/B	Hellfire	0.45419
BGM-71A	TOW I	0.27860
BGM-71D	TOW II	0.84932
–	MLRS	0.57514
M-712	Copperhead CLGP	0.45419
–	5" Deadeye SALGP	0.52415

IV-22 The data for Figure IV-12 are shown below:

Characteristic	Sample Size	Low	High	Mean
All–Planned	19	40.0	927.0	280.8
All–Actual	19	62.1	1,299.9	379.5
Intercept–Planned	10	40.0	927.0	208.2
Intercept–Actual	10	62.1	1,299.9	342.8
Surface Attack–Planned	9	105.6	846.0	361.5
Surface Attack–Actual	9	179.6	895.8	420.3
Air Launched–Planned	12	40.0	927.0	309.8
Air Launched–Actual	12	62.1	1,299.9	428.1
Surface Launched–Planned	7	77.7	454.3	231.1
Surface Launched–Actual	7	179.6	466.0	296.2
Army–Planned	7	77.7	463.0	271.5
Army–Actual	7	179.6	506.8	338.7
Navy–Planned	10	40.0	846.0	228.6
Navy–Actual	10	62.1	895.8	330.4
Air Force–Planned	2	221.9	927.0	574.5
Air Force–Actual	2	236.7	1,299.9	768.3
New–Planned	10	180.3	927.0	443.0
New–Actual	10	209.7	1,299.9	553.6
Modified–Planned	9	40.0	221.9	100.6
Modified–Actual	9	62.1	356.3	186.2

IV-23. The data for Figure IV-13 are shown below. The Mann-Whitney test was interpreted using the Table of Critical Values in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Characteristic	Sample Size	Low	High	Mean	Statistical Significance	Test
All	19	0.84	4.89	1.71		
Intercept	10	0.84	4.89	2.14	.072	Kruskal-Wallis
Surface Attack	9	1.03	1.79	1.22		
Air Launched	12	0.84	4.89	1.86	.933	Kruskal-Wallis
Surface Launched	7	1.03	2.34	1.45		
Army	7	1.03	2.34	1.44	.845	Kruskal-Wallis
Navy	10	0.84	4.89	1.99	>.200	Mann-Whitney
Air Force	2	1.07	1.40	1.24		
New	10	1.03	1.54	1.26	.165	Kruskal-Wallis
Modified	9	0.84	4.89	2.20		
Operational/Technical Requirements Satisfied	7	0.84	1.70	1.27	.329	Kruskal-Wallis
Operational/Technical Requirements not Satisfied	10	1.03	4.89	1.98		

IV-24. Spearman rank correlations of development cost growth factors with development quantity growth factors are shown below. Statistical significance for categories with sample sizes of less than 10 was interpreted using the Table of Critical Values from the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small sample sizes.

Sample	Sample Size	Correlation Coefficient	Statistical Significance
All	19	+.472	4.5%
Intercept	10	+.485	14.6%
Surface Attack	9	+.367	>10.0%
Air Launched	12	+.542	7.2%
Surface Launched	7	+.589	>10.0%
New	10	+.043	89.9%
Modified	9	+.692	5.0%

IV-25. Spearman rank correlations of development cost growth factors with full scale development start dates and development schedule growth factors are shown on the next page. Statistical significance for the modified sample (of size 9) was interpreted using the Table of Critical Values from the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small sample sizes.

Measure	Sample Size	Correlation Coefficient	Statistical Significance
Development Schedule Growth			
All	19	+.267	25.8%
New	10	+.315	34.4%
Modifications	9	+.467	>10.0%
Full Scale Development Start Date	19	−.126	59.4%

IV-26. The data for Figure IV-14 are shown below. The Mann-Whitney tests were interpreted using the Tables of Probability and Critical Values in the *Chemical Rubber Company Handbook Tables for Probability and Statistics* for small, unequal sample sizes.

Initiatives	Sample Size	Low	High	Mean	Statistical Significance	Test
With Advanced Development Phase	12	0.98	1.54	1.22	.011	Kruskal-Wallis
Without Advanced Development Phase	7	0.84	4.89	2.54		
With Advanced Development Prototypes	10	0.98	1.54	1.21	.026	Kruskal-Wallis
Without Advanced Development Prototypes	8	0.84	4.89	2.36		
With Competitive Advanced Development	7	0.98	1.42	1.20	.638	Mann-Whitney
With Non-competitive Advanced Development	5	1.06	1.54	1.26		
With FSD Subsystem Competition	4	1.06	1.20	1.11	.050	Mann-Whitney
Without FSD Subsystem Competition	14	0.84	4.89	1.93		
With Independent Testing	3	1.07	1.54	1.34	>.200	Mann-Whitney
Without Independent Testing	14	0.84	4.89	1.76		
With Independent Cost Estimate	6	1.06	1.42	1.24	.664	Kruskal-Wallis
Without Independent Cost Estimate	10	0.84	4.89	1.97		
With System Warranties	6	0.98	4.27	1.78	1.000	Kruskal-Wallis
Without System Warranties	10	0.84	2.34	1.46		
With Subystem Warranties	3	1.42	2.34	1.93	>.100	Mann-Whitney
Without Subsystem Warranties	12	0.84	4.27	1.51		

The sample of munitions was further stratified, as shown below, in an unsuccessful attempt to separate out the effects of advanced development (with or without prototypes) from whether the munition was new or modified. None of the tests are statistically significant, and the data are not plotted in Figure IV-14.

Initiatives	Sample Size	Low	High	Mean	Statistical Significance	Test
With Advanced Development Phase						
New Munitions	10	1.03	1.54	1.26	>10.0%	Mann-Whitney
Modified Munitions	2	0.98	1.07	1.03		
With Advanced Development Prototypes						
New Munitions	8	1.03	1.54	1.25	17.8%	Mann-Whitney
Modified Munitions	2	0.98	1.07	1.03		
Without Advanced Development Prototypes						
New Munitions	1	1.16	1.16	1.16	50.0%	Mann-Whitney
Modified Munitions	7	0.84	4.89	2.54		
New Munitions						
With Advanced Development Prototypes	8	1.03	1.54	1.25	100.0%	Mann-Whitney
Without Advanced Development Prototypes	1	1.16	1.16	1.16		
Modified Munitions						
With Advanced Development Phase & Advanced Development Prototypes	2	0.98	1.07	1.03	22.2%	Mann-Whitney
Without Advanced Development Phase or Advanced Development Prototypes	7	0.84	4.89	2.54		

IV-27. The data for Figure IV-15 are shown below. The **Mann-Whitney** test was interpreted using the Table of Critical Values in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small unequal sample sizes.

Risk Factor	Sample Size	Low	High	Mean	Statistical Significance	Test
Stable Threat	17	0.84	4.89	1.76	>.200	Mann-Whitney
Unstable Threat	2	1.07	1.42	1.25		
Technology Advance Subsample	11	1.07	2.34	1.47	.457	Kruskal-Wallis
Remainder of Sample	8	0.84	4.89	2.04		
Minor Performance Advance	1	1.09	1.09	1.09	.395	Kruskal-Wallis
Substantial Performance Advance	4	1.07	1.70	1.40		
Extensive Performance Advance	6	1.28	2.34	1.57		
No Materials Advance	1	1.67	1.67	1.67	.470	Kruskal-Wallis
Minor Materials Advance	1	1.09	1.09	1.09		
Substantial Materials Advance	5	1.16	1.70	1.45		
Extensive Materials Advance	4	1.07	2.34	1.53		
Minor Production Advance	2	1.67	1.70	1.69	.134	Mann-Whitney
Substantial Production Advance	6	1.07	1.54	1.29		
Extensive Production Advance	3	1.28	2.34	1.68		
Procurement Funding Micro-Stability Subsample	11	0.98	2.04	1.38	.620	Kruskal-Wallis
Remainder of Sample	8	0.84	4.89	2.16		
Develop./Prod. Overlap Subsample	12	0.98	4.89	1.67	.800	Kruskal-Wallis
Remainder of Sample	7	0.84	4.27	1.77		

Since the technological advance subsample and the development/production overlap subsample (both discussed in Chapter III) are not significantly different from the remainder of the sample, as shown above and in Figure IV-16, they are representative of the entire sample; inferences drawn about these two subsamples should be applicable to the entire sample. Since the resource requirements were obtained from the same representative subsample of munitions as were the required levels of technological advance, any inferences drawn about the resource requirements subsample should also be applicable to the entire sample.

IV-28. Spearman rank correlations of development cost growth factors with the percentage requirements for new resources are shown below:

Measure	Sample Size	Correlation Coefficient	Statistical Significance
Percentage Requirements for New Resources			
Test Equipment	11	–.509	10.7%
Facilities	11	–.627	4.7%
Tooling	11	–.382	22.7%

V-29. The Spearman rank correlation of development cost growth factors with the development/production overlap ratios described in Chapter III is shown below:

Risk Measure	Sample Size	Correlation Coefficient	Statistical Significance
Concurrency Ratio	12	+.070	81.7%

IV-30. The production costs in 1989 dollars shown in Table IV-8 for each munition are based on the then-year costs shown in the individual munition case studies contained in Volume II of this report. Those costs were divided by escalation factors to obtain the production costs in 1989 dollars. The escalation factors are from the Office of the Assistant Secretary of Defense (Comptroller) and are shown below:

Designator	Title	Escalation Factor
A/RIM-7E	Sparrow III-B CW	0.25339
AIM-7F	Sparrow III Pulse Doppler	0.25339
A/RIM-7M	Sparrow III Monopulse	0.52259
AIM-9L	Sidewinder	0.28822
AIM-9M	Sidewinder	1.00000
AIM-54A	Phoenix	0.21589
AIM-54C	Phoenix	0.47191
AIM-120A	AMRAAM	0.52698
FIM-92A	Stinger-Basic	0.30756
FIM-92A	Stinger-POST/RMP	0.30756
AGM-65D/F/G	IIR Maverick	0.39947
A/R/UGM-84A/C/D	Harpoon	0.27497
AGM-88A	HARM	0.52259
AGM-114A/B	Hellfire	0.58405
BGM-71A	TOW I	0.28613
BGM-71D	TOW II	0.84734
–	MLRS	0.52118
M-712	Copperhead CLGP	0.39724
–	5" Deadeye SALGP	0.47191

IV-31. The data for Figure IV-16 are shown below:

Characteristic	Sample Size	Low	High	Mean
All–Planned	12	510	2,784	1,546
All–Current	12	710	4,151	2,354
Intercept–Planned	6	629	2,049	1,128
Intercept–Current	6	710	2,768	1,644
Surface Attack–Planned	6	510	2,784	1,965
Surface Attack–Current	6	820	4,151	3,064
Air Launched–Planned	9	510	2,784	1,451
Air Launched–Current	9	710	3,866	2,230
Surface Launched–Planned	3	1,087	2,553	1,833
Surface Launched–Current	3	1,575	4,151	2,725
Army–Planned	4	510	2,553	1,502
Army–Current	4	820	4,151	2,249
Navy–Planned	7	655	2,784	1,473
Navy–Current	7	710	3,866	2,246
Air Force–Planned	1	2,241	2,241	2,241
Air Force–Current	1	3,532	3,532	3,532
New–Planned	6	510	2,784	1,689
New–Current	6	820	4,151	2,791
Modified–Planned	6	629	2,553	1,404
Modified–Current	6	710	3,532	1,917

IV-32. The data for Figure IV-17 are shown below. The Mann-Whitney tests were interpreted using the Tables of Probability and Critical Values in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Characteristic	Sample Size	Low	High	Mean	Statistical Significance	Test
All	12	0.96	2.23	1.58		
Intercept	6	1.01	2.12	1.54	.631	Mann-Whitney
Surface Attack	6	0.96	2.23	1.62		
Air Launched	9	1.01	2.12	1.59	>.200	Mann-Whitney
Surface Launched	3	0.96	2.23	1.55		
Army	4	0.96	2.23	1.56	.928	Mann-Whitney
Navy	7	1.01	2.12	1.59		
Air Force	1	1.58	1.58	1.58	1.000	Mann-Whitney
New	6	1.35	2.23	1.66	.423	Kruskal-Wallis
Modified	6	0.96	2.12	1.50		
Operational/Technical Requirements Satisfied	4	1.45	2.23	1.82	.154	Mann-Whitney
Operational/Technical Requirements Not Satisfied	8	0.96	2.12	1.46		

IV-33. The Spearman rank correlation of production cost growth factors with development schedule growth factors is shown below:

Measure	Sample Size	Correlation Coefficient	Statistical Significance
Development Schedule Growth	12	+.692	2.2%

IV-34. Spearman rank correlations of production cost growth factors with development cost growth factors, development quantity growth factors, and production start dates are shown below. Statistical significance for the new and modified samples (of size 6) were interpreted using the Table of Critical Values from the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small sample sizes.

Measure	Sample Size	Correlation Coefficient	Statistical Significance
Development Quantity Growth			
All	12	−.063	41.8%
New	6	−.200	>10.0%
Modified	6	+.372	>10.0%
Development Cost Growth	12	−.105	72.8%
Production Start Date	12	−.357	23.7%

IV-35. The data for Figure IV-18 are shown on the next page. The Mann-Whitney tests were interpreted using the Tables of Probabilities and Critical Values in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Initiative	Sample Size	Low	High	Mean	Statistical Significance	Test
With Advanced Development Phase	8	1.31	2.23	1.61	.808	Mann-Whitney
Without Advanced Development Phase	4	0.96	2.12	1.53		
With Advanced Development Prototypes	7	1.31	2.23	1.63	.788	Mann-Whitney
Without Advanced Development Prototypes	4	0.96	2.12	1.53		
With Competitive Advanced Development	4	1.31	2.23	1.64	1.000	Mann-Whitney
With Non-Competitive Advanced Development	4	1.35	1.93	1.58		
With FSD Subsystem Competition	3	1.58	1.93	1.71	>.200	Mann-Whitney
Without FSD Subsystem Competition	9	0.96	2.23	1.54		
With Independent Testing	3	1.35	1.58	1.44	.630	Mann-Whitney
Without Independent Testing	8	0.96	2.23	1.65		
With Independent Cost Estimate	4	1.39	2.23	1.70	.610	Mann-Whitney
Without Independent Cost Estimate	6	0.96	2.12	1.56		
With Low-Rate Initial Production Phase	7	1.35	2.23	1.73	.667	Mann-Whitney
Without Low-Rate Initial Production Phase	3	0.96	2.12	1.51		
With System Production Competition	5	1.01	2.12	1.53	.808	Mann-Whitney
Without System Production Competition	7	0.96	2.23	1.62		
With Subsystem Production Competition	8	0.96	2.12	1.50	.460	Mann-Whitney
Without Subsystem Production Competition	4	1.35	2.23	1.74		
With Multi-Year Production Contracting	3	0.96	2.23	1.59	>.200	Mann-Whitney
Without Multi-Year Production Contracting	9	1.01	2.12	1.58		
With System Warranties	5	1.31	2.23	1.70	.222	Mann-Whitney
Without System Warranties	5	0.96	1.93	1.34		
With Subystem Warranties	2	1.01	1.39	1.20	.400	Mann-Whitney
Without Subsystem Warranties	8	0.96	2.23	1.60		
With Foreign Production	3	0.96	2.12	1.51	>.200	Mann-Whitney
Without Foreign Production	9	1.01	2.23	1.60		

IV-36. The data for Figure IV-19 are shown on the next page. The Mann-Whitney tests were interpreted using the Tables of Probabilities and Critical Values in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Risk Factor	Sample Size	Low	High	Mean	Statistical Significance	Test
Technology Advance Subsample	8	0.96	2.23	1.57	.934	Mann-Whitney
Remainder of Sample	4	1.01	2.12	1.59		
Minor Performance Advance	1	1.61	1.61	1.61	.806	Kruskal-Walis
Substantial Performance Advance	3	0.96	2.01	1.52		
Extensive Performance Advance	4	1.35	2.23	1.61		
No Materials Advance	1	2.01	2.01	2.01	.250	Kruskal-Wallis
Minor Materials Advance	1	1.61	1.61	1.61		
Substantial Materials Advance	3	0.96	1.45	1.25		
Extensive Materials Advance	3	1.39	2.23	1.73		
Minor Production Advance	2	0.96	2.01	1.49	.795	Kruskal-Walis
Substantial Production Advance	4	1.35	1.61	1.50		
Extensive Production Advance	2	1.39	2.23	1.81		
Production Funding Micro-Stability Subsample	10	0.96	2.23	1.55	>.200	Mann-Whitney
Remainder of Sample	2	1.35	2.12	1.74		
Develop./Prod. Overlap Subsample	11	0.96	2.23	1.60	>.200	Mann-Whitney
Remainder of Sample	1	1.35	1.35	1.35		

Since the technological advance subsample, the production funding micro-stability subsample, and the development/production overlap subsample (all discussed in Chapter III) are not significantly different from the remainder of the sample, as shown above and in Figure IV-19, they are all representative of the entire sample; inferences drawn about these three subsamples should be applicable to the entire sample. Since the resource requirements were obtained from the same representation subsample of munitions as were the required levels of technological advance, any inferences drawn about the resource requirements subsample should also be applicable to the entire sample.

IV-37. Spearman rank correlations of production cost growth factors with the percentage requirements for new resources, are shown below. Statistical significance was interpreted using the Table of Critical Values from the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small sample sizes.

Risk Measure	Sample Size	Correlation Coefficient	Statistical Significance
Percentage Requirements for New Resources			
Test Equipment	8	−.072	>10.0%
Facilities	8	+.488	>10.0%
Tooling	8	+.048	>10.0%

IV-38. Spearman rank correlations of production cost growth factors with the procurement funding stability measures described in Chapter III are shown below:

Risk Measure	Sample Size	Correlation Coefficient	Statistical Significance
Procurement Funding Stability			
Macro	12	+.546	7.0%
Micro	10	+.133	68.9%

IV-39. The Spearman rank correlation of production cost growth factors with the development/production overlap ratios described in Chapter III is shown below:

Risk Measure	Sample Size	Correlation Coefficient	Statistical Significance
Concurrency	11	+.600	5.8%

IV-40. The data for Figure IV-20 are shown below:

Characteristic	Size	Sample Low	High	Mean
All–Planned	17	705	362,832	63,843
All–Actual	17	2,285	452,322	59,042
Intercept–Planned	9	705	57,773	15,968
Intercept–Actual	9	2,285	50,640	15,105
Surface Attack–Planned	8	2,870	362,832	117,703
Surface Attack–Actual	8	3,971	452,322	108,471
Air Launched–Planned	11	705	57,773	15,513
Air Launched–Actual	11	2,285	60,664	19,371
Surface Launched–Planned	6	22,387	362,832	152,448
Surface Launched–Actual	6	8,085	452,322	131,773
Army–Planned	7	22,387	362,832	134,184
Army–Actual	7	8,085	452,322	119,905
Navy–Planned	9	705	57,773	12,774
Navy–Actual	9	2,285	19,961	11,524
Air Force–Planned	1	31,078	31,078	31,078
Air Force–Actual	1	60,664	60,664	60,664
New–Planned	8	2,870	362,832	99,330
New–Actual	8	2,285	452,322	86,452
Modified–Planned	9	705	141,224	32,299
Modified–Actual	9	3,356	125,856	34,678

IV-41. The data for Figure IV-21 are shown below. The Mann-Whitney test was interpreted using the Table of Critical Values in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Characteristic	Sample Size	Low	High	Mean	Statistical Significance	Test
All	17	0.19	4.76	1.42		
Intercept	9	0.34	4.76	1.65	.531	Kruskal-Wallis
Surface Attack	8	0.19	1.98	1.16		
Air Launched	11	0.34	4.76	1.73	.056	Kruskal-Wallis
Surface Launched	6	0.19	1.90	0.86		
Army	7	0.19	1.98	1.02	.266	Kruskall-Wallis
Navy	9	0.34	4.76	1.67		
Air Force	1	1.95	1.95	1.95	>.200	Mann-Whitney
New	8	0.19	1.98	0.97	.112	Kruskal-Wallis
Modified	9	0.34	4.76	1.82		
Operational/Technical Requirements Satisfied	6	0.19	4.76	1.41	.233	Kruskal-Wallis
Operational/Technical Requirements not Satisfied	10	0.59	2.27	1.38		

IV-42. The Spearman rank correlation of production quantity growth factors with production cost growth factors is shown below:

Measure	Sample Size	Correlation Coefficient	Statistical Significance
Production Cost Growth	12	+.014	96.3%

IV-43. Spearman rank correlations of production quantity growth factors with development cost growth factors, development schedule growth factors, and production start dates, are shown below:

Measure	Sample Size	Correlation Coefficient	Statistical Significance
Development Cost Growth	17	+.211	39.9%
Development Schedule Growth	17	+.012	96.1%
Production Start Date	17	+.538	3.1%

IV-44. The data for Figure IV-22 are shown on the next page. The Mann-Whitney test was interpreted using the Table of Critical Values in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal size.

Initiative	Sample Size	Low	High	Mean	Statistical Significance	Test
With Low-Rate Initial Production Phase	8	0.19	4.76	1.69	.203	Kruskal-Wallis
Without Low-Rate Initial Production Phase	7	0.34	1.90	0.99		
With System Production Competition	9	0.59	2.27	1.58	.048	Kruskal-Wallis
Without System Production Competition	8	0.19	4.76	1.24		
With Subsystem Production Competition	10	0.89	4.76	1.91	.006	Kruskal-Wallis
Without Subsystem Production Competition	6	0.19	1.38	0.64		
With Multi-Year Production Contracting	5	0.19	1.90	0.96	.200	Mann-Whitney
Without Multi-Year Production Contracting	12	0.34	4.76	1.61		
With System Warranties	6	0.19	4.76	1.83	.316	Kruskal-Wallis
Without System Warranties	9	0.34	2.27	1.11		
With Subsystem Warranties	3	1.05	2.27	1.74	>.200	Mann-Whitney
Without Subsystem Warranties	12	0.19	4.76	1.31		
With Foreign Production	6	0.34	1.25	0.78	.021	Kruskal-Wallis
Without Foreign Production	11	0.19	4.76	1.77		

IV-45. The data for Figure IV-23 are shown below:

Risk Factor	Sample Size	Low	High	Mean	Statistical Significance	Test
Technology Advance Subsample	9	0.19	4.76	1.56	.995	Kruskal-Wallis
Remainder of Sample	8	0.34	2.27	1.26		
Minor Performance Advance	1	1.98	1.98	1.98	.200	Kruskal-Wallis
Substantial Performance Advance	3	0.89	4.76	2.53		
Extensive Performance Advance	5	0.19	1.90	0.89		
No Materials Advance	1	4.76	4.76	4.76	.174	Kruskal-Wallis
Minor Materials Advance	1	1.98	1.98	1.98		
Substantial Materials Advance	3	0.35	0.98	0.74		
Extensive Materials Advance	4	0.19	1.95	1.27		
Minor Production Advance	2	0.39	4.76	2.83	.705	Kruskal-Wallis
Substantial Production Advance	4	0.35	1.98	1.32		
Extensive Production Advance	3	0.19	1.90	1.05		
Production Funding Micro-Stability Subsample	10	0.19	4.76	1.62	.380	Kruskal-Wallis
Remainder of Sample	7	0.34	1.66	1.14		

Since the technological advance subsample and the production funding micro-stability subsample (both discussed in Chapter III) are not significantly different from the remainder of the sample, as shown above and in Figure IV-23, they are both representative of the entire sample; inferences drawn about these two subsamples should be applicable to the entire sample. Since the resource requirements were obtained from the same representative subsample of munitions as were the required levels of technological advance, any inferences drawn about the resource requirements subsample should also be applicable to the entire sample.

IV-46. Spearman rank correlations of production quantity growth factors with the percentage requirements for new resources are shown below. Statistical significance was interpreted using the Table of Critical Values from the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small sample sizes.

Measure	Sample Size	Correlation Coefficient	Statistical Significance
Percentage Requirements for New Resources			
Test Equipment	9	+.108	>10.0%
Facilities	9	+.108	>10.0%
Tooling	9	−.183	>10.0%

IV-47. Spearman rank correlations of production quantity growth factors with the procurement funding stability measures described in Chapter III are shown below:

Risk Measure	Sample Size	Correlation Coefficient	Statistical Significance
Procurement Funding Stability			
Macro	17	−.106	67.2%
Micro	10	−.215	64.5%

IV-48. This is equivalent to:

$$\frac{\text{(Currently planned production span/currently planned production quantity)}}{\text{(Originally planned production span/originally planned production quantity)}}$$

and is a measure of the change in the amount of time for production of one unit.

IV-49. The data for Figure IV-24 are shown on the next page. The Mann-Whitney test was interpreted using the Table of Critical Values in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Characteristic	Sample Size	Low	High	Mean	Statistical Significance	Test
All	17	0.34	9.15	21.9		
Intercept	9	0.34	9.15	2.16	.149	Kruskal-Wallis
Surface Attack	8	1.10	5.56	2.22		
Air Launched	11	0.34	9.25	1.96	.209	Kruskal-Wallis
Surface Launched	6	0.88	5.56	2.61		
Army	7	0.88	5.56	2.41	.290	Kruskal-Wallis
Navy	9	0.34	9.15	2.14	>.200	Mann-Whitney
Air Force	1	1.10	1.10	1.10		
New	8	1.00	5.56	2.40	.112	Kruskal-Wallis
Modified	9	0.34	9.15	2.00		
Operational/Technical Requirements Satisfied	6	0.34	9.15	3.39	.356	Kruskal-Wallis
Operational/Technical Requirements not Satisfied	10	0.74	3.85	1.60		

IV-50. The Spearman rank correlation of production stretchout factors with production quantity growth factors is shown below:

Measure	Sample Size	Correlation Coefficient	Statistical Significance
Production Quantity Growth	17	–.783	0.2%

IV-51. The Spearman rank correlation of production stretchout factors with production cost growth factors is shown below:

Measure	Sample Size	Correlation Coefficient	Statistical Significance
Production Cost Growth	12	+.378	21.0%

A linear regression equation was also calculated, and is shown below, with the values of the t-statistics shown in parentheses below the coefficients.

$$\text{Production Cost Growth} = \underset{(7.67)}{1.29} + \underset{(2.16)}{.176}\ \text{production stretchout}$$

Unfortunately, the data do not even come close to satisfying the regression analysis requirements for Gaussian (or normal, i.e., bell-shaped) distributions of residuals. Part of the problem could be the small sample size.

IV-52. The Spearman rank correlation of production stretchout factors with production start dates is shown below:

Measure	Sample Size	Correlation Coefficient	Statistical Significance
Production Start Date	17	–.433	8.4%

IV-53. The data for Figure IV-25 are shown below. The Mann-Whitney test was interpreted using the Table of Critical Values in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Initiative	Sample Size	Low	High	Mean	Statistical Significance	Test
With Low-Rate Initial Production Phase	8	0.34	5.56	1.74	.325	Kruskal-Wallis
Without Low-Rate Initial Production Phase	7	0.74	9.15	3.01		
With System Production Competition	9	0.74	3.85	1.49	.211	Kruskal-Wallis
Without System Production Competition	8	0.34	9.15	2.97		
With Subsystem Production Competition	10	0.34	2.25	1.14	.017	Kruskal-Wallis
Without Subsystem Production Competition	6	1.00	9.15	4.11		
With Multi-Year Production Contracting	5	0.88	5.56	2.56	>.200	Mann-Whitney
Without Multi-Year Production Contracting	12	0.34	9.15	2.03		
With System Warranties	6	0.34	5.56	1.71	.316	Kruskal-Wallis
Without System Warranties	9	0.88	9.15	2.61		
With Subsystem Warranties	3	0.88	1.31	1.09	>.200	Mann-Whitney
Without Subsystem Warranties	12	0.34	9.15	2.55		
With Foreign Production	6	1.19	9.15	3.44	.018	Kruskal-Wallis
Without Foreign Production	11	0.34	5.56	1.51		

IV-54. The data for Figure IV-26 are shown below:

Risk Factor	Sample Size	Low	High	Mean	Statistical Significance	Test
Technical Advance Subsample	9	0.34	5.56	1.73	.500	Kruskal-Wallis
Remainder of Sample	8	0.74	9.15	2.70		
Minor Performance Advance	1	1.20	1.20	1.20	.645	Kruskal-Wallis
Substantial Performance Advance	3	0.34	1.31	0.92		
Extensive Performance Advance	3	0.88	5.56	2.32		
No Materials Advance	1	0.34	0.34	0.34	.474	Kruskal-Wallis
Minor Materials Advance	1	1.20	1.20	1.20		
Substantial Materials Advance	4	1.00	2.86	1.72		
Extensive Materials Advance	3	0.88	5.56	2.21		
Minor Production Advance	2	0.34	1.31	0.83	.705	Kruskal-Wallis
Substantial Production Advance	4	1.00	2.86	1.54		
Extensive Production Advance	3	0.88	5.56	2.58		
Procurement Funding Micro-Stability Subsample	10	0.34	5.56	1.81	.922	Kruskal-Wallis
Remainder of Sample	7	0.74	9.15	2.72		
Develop./Prod. Overlap Subsample	11	0.34	5.56	1.85	.615	Kruskal-Wallis
Remainder of Sample	6	0.74	9.15	2.80		

IV-55. Spearman rank correlations of production stretchout factors with percentage requirements for new resources are shown below. Statistical significance was interpreted using the Table of Critical Values from the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small sample sizes.

Risk Measure	Sample Size	Correlation Coefficient	Statistical Significance
Percentage Requirements for New Resources			
Test Equipment	9	+.108	>10.0%
Facilities	9	+.388	>10.0%
Tooling	9	+.421	>10.0%

IV-56. Spearman rank correlations of production stretchout factors with the procurement funding stability measures and development/production overlap ratios described in Chapter III are shown below:

Risk Measure	Sample Size	Correlation Coefficient	Statistical Significance
Procurement Funding Stability			
Macro	17	+.148	55.3%
Micro	10	+.094	77.1%
Concurrency	11	+.177	57.5%

IV-57. The 1989-dollar total program cost entries in Table IV-22 are based on the then-year development and production costs shown in the individual munitions case studies contained in Volume II of this report. Those costs were divided by escalation factors to obtain the 1989-dollar costs for development and production. The total program cost is the sum of the development and production costs. The escalation factors for development costs are shown in Note IV-21, and the escalation factors for production costs are shown in Note IV-30.

IV-58. The data for Figure IV-27 are shown below:

Characteristic	Sample Size	Low	High	Mean
All–Planned	12	695	3,184	1,812
All–Actual	12	844	4,463	2,705
Intercept–Planned	6	695	2,409	1,281
Intercept–Actual	6	844	3,320	1,898
Surface Attack–Planned	6	973	3,184	2,343
Surface Attack–Actual	6	1,326	4,463	3,511
Air Launched–Planned	9	695	3,184	1,744
Air Launched–Actual	9	844	4,463	2,610
Surface Launched–Planned	3	1,304	2,659	2,017
Surface Launched–Actual	3	1,892	4,447	2,990
Army–Planned	4	973	2,659	1,756
Army–Actual	4	1,326	4,447	2,474
Navy–Planned	7	695	3,184	1,751
Navy–Actual	7	844	4,463	2,628
Air Force–Planned	1	2,463	2,463	2,463
Air Force–Actual	1	3,768	3,768	3,768
New–Planned	6	973	3,184	2,108
New–Actual	6	1,326	4,463	3,314
Modified–Planned	6	695	2,659	1,516
Modified–Actual	6	844	3,768	2,096

IV-59. The data for Figure IV-29 are shown on the next page. The Mann-Whitney tests were interpreted using the Tables of Probabilities and Critical Values in the *Chemical Rubber Company Handbook of Tables for Probability and Statistics* for small, unequal sample sizes.

Characteristic	Sample Size	Low	High	Mean	Statistical Significance	Test
All	12	0.99	2.31	1.54		
Intercept	6	1.10	2.31	1.58	.873	Kruskal-Wallis
Surface Attack	6	0.99	2.12	1.51		
Air Launched	9	1.10	2.31	1.55	>.200	Mann-Whitney
Surface Launched	3	0.99	2.12	1.52		
Army	4	0.99	2.12	1.49	1.000	Kruskal-Wallis
Navy	7	1.10	2.31	1.58	1.000	Kruskal-Wallis
Air Force	1	1.52	1.52	1.52		
New	6	1.38	2.12	1.56	.630	Kruskal-Wallis
Modified	6	0.99	2.31	1.53		

IV-60. The Spearman rank correlation of total program cost growth factors with production cost growth factors is shown below:

Measure	Sample Size	Correlation Coefficient	Statistical Significance
Production Cost Growth	12	+.962	0.1%

IV-61. The Spearman rank correlation of total program cost growth factors with development cost growth factors is shown below:

Measure	Sample Size	Correlation Coefficient	Statistical Significance
Development Cost Growth	12	–.032	91.7%

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Appendix A

TECHNOLOGY AND RESOURCES QUESTIONNAIRE

APPENDIX A
TECHNOLOGY AND RESOURCES QUESTIONNAIRE

The questionnaire presented here was prepared in order to obtain information from contractors on how changes in technology and production capacity requirements anticipated early in the program compared with what was later actually required. Because of the many major subsystems and contractors for the munitions in the sample, attention was restricted to the guidance and control subsystems only. The guidance and control subsystem requires the largest share, by far, of both the development and procurement funding for most of the munitions in the sample. The questionnaire was submitted to the following producers of guidance and control systems for the munitions in the sample:

General Dynamics- Pomona

Hughes Aircraft

Martin-Marietta

McDonnell Douglas

Raytheon

Rockwell

Texas Instruments

Responses were provided by four of the contractors. The responses are proprietary and are contained in Volume II, Appendix A. Prior to being used in the analyses in Chapter III of this report, the response data were aggregated so as to make them unidentifiable as to contractor or munition.

Weapon =

Subsystem =

Contractor =

The purpose of this questionnaire is to obtain estimates of the extent to which changes in technology and production capacity were required for the major subsystems of the weapon. Of interest are both what was anticipated early in the program and what was subsequently actually required. Please check off the entry in each column that you think best describes the anticipated and actual requirements for each of the following:

Area	Anticipated	Actual
Technology embodied in the subsystem, as compared to technology embodied in similar subsystems that your organization was responsible for:		
1. Off the shelf, as is		
2. Minor advances (<10%) to existing technology		
3. Substantial advances (11-50%) to existing technology		
4. Extensive advances (>50%) to existing technology		
5. All new technology		
Material used in the subsystem, as compared to materials used in similar subsystems previously produced by your organization:		
1. Use of existing materials		
2. Minor use (<10%) of new materials		
3. Substantial use (11-50%) of new materials		
4. Extensive use (>50%) of new materials		
5. All new materials		

Area	Anticipated	Actual
Production processes used in manufacturing the subsystem as compared to production processes used in similar sub-systems previously manufactured by your organization:		
1. Use of existing production processes only		
2. Minor use (<10%, by value added) of new production processes		
3. Substantial use (11-50%, by value added) of new production processes		
4. Extensive use (>50%, by value added) of new production processes		
5. All new production processes		
Production facilities used in manufacturing the subsystem:		
1. Use of existing facilities only		
2. Augmentation of existing facilities (please estimate the percentage increase)		
3. All new production facililties		
Production tooling used in manufacturing the subsystem:		
1. Use of existing tooling only		
2. Augmentation of existing tooling (please estimate the percentage of $ value increase)		
3. All new production tooling		
Test equipment used in development and production of the subystems		
1. Use of existing test equipment only		
2. Augmentation of existing test equipment (please estimate the percentage of $ value increase)		
3. All new test equipment		

Appendix B

ACQUISITION CHECKLIST

APPENDIX B
ACQUISITION CHECKLIST

The acquisition checklist is an extension of the findings and recommendations contained in [B-1], augmented by decision criteria identified during the analyses for this report and identified in [B-2 through B-5]. The checklist was prepared for use by the staff of the Under Secretary of Defense for Acquisition. It is in the form of questions to be answered at the time a program is initiated and prior to approvals at Milestones I, II, IIIA, and IIIB. The checklist has been formulated as questions to be answered, rather than as conditions to be acknowledged with "yes" or "no" answers. Many checklists are in the form of conditions to be acknowledged with "yes" or "no" answers; the most common example is the aircraft pilot's checklist. That type of checklist is most applicable to situations where conditions can be easily observed or measured and a simple annotation can show that the condition has been satisfied. In a more complex situation such as a weapon acquisition program, such a checklist is too easily susceptible to superficial completion. Instead, this checklist is in a format more similar to the guides used in inspecting military units with questions that require substantive answers.

A. OVERALL PROGRAM MANAGEMENT

The questions to be answered at the time the acquisition program is initiated are concerned with the qualifications and capabilities of the program management staff. Although the appointment of a Program Manager and selection of his staff is a service prerogative, an understanding of the talents needed for successful program management is necessary, and selection of those talents should be checked in OSD.

1. What are the demonstrated leadership abilities of the program manager in:
   a. Directing his subordinates to effectively accomplish the assigned mission?
   b. Working effectively with appropriate personnel from:
      (1) potential user organizations?
      (2) relevant intelligence agencies?
      (3) superiors in the defense acquisition hierarchy?

(4) congressional bodies and staffs?

(5) contracting companies?

2. What levels of experience are available on the Program Manager's staff in:

   a. Military operations with similar weapons?

   b. Management of other acquisition programs of similar difficulty?

3. What analytic skills are available on the Program Manager's staff for:

   a. Parametric and tradeoff analyses?

   b. Cost estimating?

   c. Project planning and scheduling?

   d. Test planning and analyses?

4. What technical engineering skills are available on the Program Manager's staff for:

   a. Electronics?

   b. Software?

   c. Explosives?

   d. Propulsion?

   e. Airframe and structural?

   f. Manufacturing technology?

B. THREAT/REQUIREMENT/TECHNOLOGY

The following questions should be answered when the project is initiated, and should be reanswered at each of Milestones I, II, IIIA, and IIIB, (i.e., before approval to commence concept demonstration and validation, full scale development, low-rate initial production, and full-rate production).

1. How do the Program Manager, users, and contractor(s) interpret the threat and how the threat is likely to change in the future in terms of:

   a. Target characteristics?

   b. Target environment?

   c. Numbers of targets?

   d. Possible countermeasures against the weapon?

2. What are the reactions of the user community to the program?

3. Are the system concept, design, cost, and schedule for development, testing, and production consistent with historical data from other similar systems, and if not, why?

4. What are the current initial operational capability (IOC) estimates of complimentary systems that will be used with the weapons (in particular, platforms, target acquisition systems, and target designation systems), and are these consistent with the current IOC estimate for the weapon:

   a. If the weapon IOC is on the critical path, what would be the cost increase (expected and variance) to achieve the same IOC as the next critical complementary system?

   b. If the weapon IOC is on a slack path, what would be the cost savings (expected and variance) from eliminating the slack?

5. What are the potential contractors' demonstrated capabilities to complete projects requiring similar technology and advances in technology within performance, schedule, and cost requirements for each subsequent phase of the program?

6. How have the potential contractors performed in management of high-risk programs?

7. What augmentation of contractor and government-owned facilities will be required for each subsequent phase of the program?

8. What augmentation of equipment and tooling will be required for each subsequent phase of the program; what are the sources of this equipment and tooling; will this program significantly affect the availability and costs of this equipment and tooling; and what will be the effects on other programs?

9. What augmentation of critically skilled personnel will be required for each subsequent phase of the program; where will they come from; what special training will be required; and what will be the effect on other programs?

10. What cost inflation rates have been allowed for?

C. MILESTONE I

The purposes of the next group of questions are to ensure that the technology to be embodied in the weapon and the technology to be used in producing the weapon will be adequately developed and demonstrated so that any significant risks or uncertainties of design, production, and operational support will be eliminated prior to engineering development.

1. What are the concept alternatives, and:

   a. What alternatives were selected for demonstration and validation, and why?

   b. What alternatives were rejected for demonstration and validation, and why?

   c. What relevant work on these alternatives is being done by other military services, government agencies, private industry, and research institutions, domestic and foreign?

2. For each alternative concept:

   a. What are the tradeoffs between performance measures?

   b. How is the expected ability to meet the threat affected by varying the performance measures, and what are the levels of uncertainly?

   c. How would the concept be used?

   d. What are the expected IOC and inventory objective dates, what are the schedule risks/uncertainties, and what are the schedule drivers?

   e. What are the expected development and production costs, what are the cost risks/uncertainties, and what are the cost drivers?

   f. What are the tradeoffs between performance, schedule, and costs?

   g. What actions would reduce the risks/uncertainties, and have contractor(s) demonstrated the capabilities to successfully accomplish these actions?

   h. What are the alternatives for supporting the weapon?

   i. What are the expected failure rates, and what are the risks/uncertainties?

   j. What are the expected support costs, and what are the risks/uncertainties?

   k. What tests and demonstrations will be required for technology development, and resolution of performance (including failure rates), production, schedule, and cost uncertainties?

   l. At what times and at what throughput rates will testing be required?

   m. Who will perform the testing, how will their other workload be affected, what throughput times can they produce, and what will be the effects on other acquisition projects?

3. For each alternative, what technological advance will be required for:

   a. Each of the subsystems in the weapon?

   b. The production process for each of the subsystems in the weapon?

4. When evaluating the alternatives:
   a. What, if any, prototypes will be required?
   b. What experiments or tests will be required?
   c. What data will be required?
   d. What will the evaluation methodology be?
5. What are the benefits and costs of sole-source demonstration and validation vs. competitive demonstration and validation?

D. MILESTONE II

The purposes of the next group of questions are to ensure that prior to starting full scale development (FSD), the technology to be embodied in the weapon and the technology to be used in producing the weapon have been adequately developed and demonstrated, and that technical and interface specifications have been formulated that will enable a weapon to be designed that meets performance, schedule, and cost requirements.

1. What are the technical and system interface specifications, as determined from the demonstration and validation phase, and:
   a. Are these firm enough to allow full scale development to proceed?
   b. Are these unnecessarily rigid and/or unproducible?
2. What levels have the risks or uncertainties been reduced to during the demonstration and validation phase, and how was this done for:
   a. Weapon performance, schedule, and cost?
   b. Production technology?
   c. Support requirements?
3. For each category of testing that was done in the demonstration and validation phase:
   a. How realistic was the testing, in terms of the test environments as compared to potential operational environments?
   b. What performance was demonstrated?
   c. Was the technology tested representative of the technology to be used?

4. For each subsystem of the weapon:

   a. What will the technology be?

   b. What similar subsystems for other weapons, or what prototypes for this subsystem have the contractor(s) built?

   c. What similar subsystems are already in existence, and if they were rejected for incorporation in the weapon, why?

   d. What relevant work is being done by other military services, government agencies, private industry, and research institutions, domestic and foreign?

   e. What materials will be processed with what production technology for the critical areas of each subsystem?

   f. What previous experiences have the contractor(s) had in processing these materials with these production technologies, and what have the throughput and yield rates been?

   g. What are the other uses of these materials and production processes, will the program significantly affect their availabilities and costs, and what will be the effects, if any, on other acquisition programs?

   h. Are the expected costs and productivity measures consistent with what is being experienced with similar materials and processes in other military and industrial applications (both domestic and foreign)?

   i. How will test articles be produced, in contrast to how operational weapons will be produced?

5. For each subsystem of the weapon, and for the weapon as a whole:

   a. What development testing will be required during FSD, at what times, and at what rates?

   b. Who will perform the testing, how will their other workload be affected, what throughput times can they produce, and what will be the effects on other acquisition programs?

   c. How will the operational suitability be demonstrated to the satisfaction of the potential users, OSD, and Congress?

   d. What other critical resources will be required during FSD (e.g., super-computing for numerical analysis or finite element analysis), at what times, and at what rates?

   e. Who will provide these other critical resources, how will their other workload be affected, what throughput times can they produce, and what will be the effects on other acquisition programs?

6. What design procedures have been implemented to ensure that the weapon will be:

   a. Testable, using the test equipment available in the production, storage, and operational environments?

   b. Producible?

   c. Reliable in both operational and storage environments?

   d. Maintainable in both operational and storage environments?

7. What are the benefits and costs of sole-source FSD vs. competitive FSD?

8. What procedures have been implemented to obtain appropriate documentation from FSD to allow competitive or foreign production of:

   a. The entire weapon?

   b. Some or all of the subsystems of the weapon?

E. MILESTONE IIIA

The purposes of the next group of questions are to ensure, prior to starting limited production and deployment, that a weapon has been designed that meets operational and performance requirements, is producible within quality, schedule, and cost requirements, and is supportable at reasonable costs.

1. How has it been demonstrated that the weapon is:

   a. Producible, within schedule and cost requirements?

   b. Supportable, within life-cycle-cost requirements and the planned logistics infrastructure?

   c. Usable by combat personnel?

   d. Useful in combat environments?

   e. Storable, while awaiting combat?

2. What fabrication methods will be used in low-rate initial production:

   a. How do these differ from the fabrication methods used in development?

   b. How have they been demonstrated?

3. What are the lead times for, and when will be the availability of:

   a. Production facilities for low-rate initial production?

   b. Test equipment for low-rate initial production?

   c. Production tooling for low-rate initial production?

d. Production materials for low-rate initial production?

e. Production labor for low-rate initial production?

f. Facilities for early operational support?

g. Test equipment for early operational support?

h. Support equipments for early operational support?

i Training of operations and support personnel for early operational support?

4. How much slack has been provided in the production schedule for unforeseen problems?

5. What procedures have been implemented to ensure quality control of the production process during low-rate initial production?

6. What procedures have been implemented, and what resources have been obtained for early operational support?

7. What procedures have been implemented to obtain data from OT&E and early operational experience for use in:

   a. Developing engineering fixes?

   b. Validating operational tactics and training requirements?

   c. Validating requirements for spare parts and maintenance capacity?

F. MILESTONE IIIB

The purposes of the final group of questions are to ensure that any necessary engineering fixes identified during OT&E and early operational experience be incorporated into the weapon before start of full-rate production (FRP), and that production be of a high quality and at the lowest cost consistent with usage and inventory objectives.

1. What requirements for engineering fixes have been identified during OT&E and early operational experience, and how are they to be satisfied; what are the operational and cost implications of satisfying them prior to FRP versus after FRP has been achieved?

2. What fabrication methods will be used in FRP, and:

   a. How do they differ from the fabrication methods used in low-rate initial production and development?

   b. How have they been demonstrated?

3. What production tolerances have been achieved during low-rate initial production, and:
   a. How do actual tolerances differ from specified tolerances?
   b. What are the schedule and cost implications?
4. What yields and throughput times have been achieved during low-rate initial production, and:
   a. How do actual yields differ from planned yields?
   b. How do actual throughput times differ from planned throughput times?
   c. What are the schedule and cost implications?
5. For each piece of special tooling and test equipment used during low-rate initial production:
   a. To what extent have required specifications been achieved?
   b. What is the effect on yield and throughput rates, and on schedule and costs?
6. What are the costs and flow rates of alternative production processes?
7. What is the lowest cost production rate, and:
   a. What degree of variability in production rate is allowed at the lowest cost rate?
   b. What are the costs of allowing for additional variability in production rates?
   c. How much slack is provided at these rates for unforeseen problems?
8. What are the comparative benefits and costs of:
   a. Single source production?
   b. Single source multiple year production?
   c. Competitive shared production?
   d. Winner-take-all production competition?
9. What are the lead times for, and when will be the availability of:
   a. Production facilities for FRP?
   b. Production equipments for FRP?
   c. Production material for FRP?
   d. Production labor for FRP?
   e. Organizational operating facilities?

f. Organizational test equipment?

g. Operational support equipment and tools?

h. Organizational level spares inventories?

i. Depot and intermediate-level facilities?

j. Depot and intermediate-level test equipment?

k. Depot and intermediate-level support equipment and tools?

l. Depot and intermediate-level spares inventories?

m. Training of operations and support personnel?

10. What procedures have been implemented by each contractor to ensure quality control of the production process during FRP?

11. What procedures have been implemented to obtain data from operational experience for use in:

 a. Developing engineering fixes?

 b. Validating operational tactics and training requirements?

 c. Validating requirements for spare parts and maintenance capacity?

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ABBREVIATIONS

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AD	advanced development
AMRAAM	Advanced Medium-Range Air-to-Air Missile
CLGP	Cannon-Launched Guided Projectile
CW	continuous wave
DAES	Defense Acquisition Executive Summary
DCP	Development Concept Paper
DDR&E	Director of Defense Research and Engineering
DoD	Department of Defense
FRP	full-rate production
FSD	full scale development
HARM	High-Speed Anti-Radiation Missile
IIR	imaging infrared
IOC	initial operational capability
LCC	life-cycle cost
LRIP	Low Rate Initial Production
MLRS	Multiple-Launch Rocket System
OSD	Office of the Secretary of Defense
OT&E	operational test and evaluation
POST	Passive Optical Seeker Technique
RMP	Reprogrammable Microprocessor
SALGP	Semi-Active Laser Guided Projectile
SAR	Selected Acquisition Reports
TOA	total obligational authority
TOW	tube-launched, optically tracked, wire-guided